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SPECIAL REPORT SERIES

No. 288

The Effect of Sugar Supplements on Dental Caries in Children

J. D. KING, MAY MELLANBY,
H. H. STONES and H. N. GREEN

CFTRI-MYSORE
6668
Effect of sugar

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1955
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J. D. KING, MAY MELLANBY,
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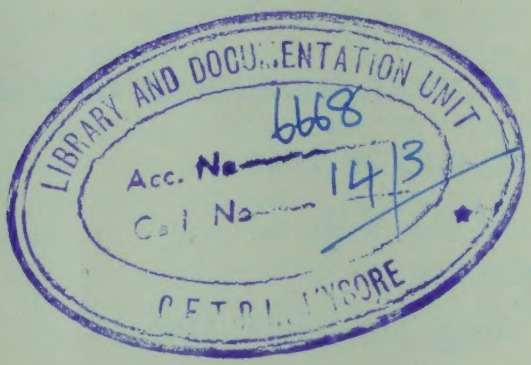

LONDON: HER MAJESTY'S STATIONERY OFFICE
1955

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PREFACE

In spite of many years of observation and research on dental caries, the environmental factors influencing the onset of the disease and the processes involved in its initiation and spread have not been fully explained by any of the theories so far put forward. During the present century numerous workers have tried to establish a relationship between caries and carbohydrates, especially refined carbohydrates such as sugar, and it is with this aspect of the problem that the Council have been concerned.

As long ago as 1928, the Council's Committee for the Investigation of Dental Disease studied the effect on children's teeth of adding treacle to the diet. They found that, though the carious process appeared to be intensified to some extent in the deciduous teeth, it was retarded in the permanent dentition, so that the carbohydrate supplement could not be said to have had any decisive effect. In 1946 the late Dr. J. D. King, a member of the Council's staff, made a small, well-controlled study on young children in residential homes, and concluded that, under the conditions prevailing in the homes, dietary supplements in the form of sweets and sugar-coated biscuits, even when given at bedtime, did not increase the incidence of caries.

Clearly, however, trials on a larger scale were desirable, and, when the Council's Dental Research Committee was re-formed in 1947, one of its first decisions was to arrange an investigation to assess the possible effects on caries experience of modifying the carbohydrate content of the diet or the manner in which carbohydrate products were given. Accordingly, groups of children in residential homes in the London area, in Liverpool and in Sheffield were observed over a maximum period of two years by four members of the Committee, the authors of the present Report. The children, who were living on basal diets of a good nutritional standard, were for the purposes of the investigation divided into control and test groups, the latter being given extra sugar as part of the diet; a certain number of the London children received the supplement in the form of unrefined sugar. The results of the survey show that, under these conditions, the increased consumption of sugar, whether refined or unrefined, has had no significant effect on the development of dental caries during the period of observation, a finding which confirms the earlier work of the Council's Dental Committee and of Dr. King.

The investigation cannot be said to prove that sugar, however distributed and however eaten, will never affect the teeth; but, to quote the authors, "it certainly points to the practical conclusion that, provided a child is fed on a diet as good as that of the average children's residential institution in England, a substantial increase in the amount of sugar in the diet will not affect the child's liability to dental caries within a period of at least two years". The Council believe that the detailed account of the investigation given in this Report will be of value in helping to prepare the way for further research on this important subject.

MEDICAL RESEARCH COUNCIL,
38 Old Queen Street,
London, S.W.1.

February 3rd, 1955

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THE EFFECT OF SUGAR SUPPLEMENTS ON DENTAL CARIES IN CHILDREN

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I. Introduction

For more than half a century it has been widely believed that dental caries is due to the dissolution of the inorganic constituents of the enamel by the acid products of fermentation in the mouth. This hypothesis evolved from a series of investigations made in the later part of the nineteenth century, and culminated in the postulation by Miller (1890) of the so-called 'chemicoparasitic' theory of caries. Since test-tube mixtures of saliva and bread, sugar or other carbohydrate-containing foods underwent fermentation on incubation at body temperature, and since teeth immersed in such mixtures became demineralized by the organic acids produced, Miller suggested that a similar fermentation occurred, resulting in destruction of the enamel, when carbohydrate foodstuffs, especially starch, were allowed to collect about the teeth. As a result of Miller's work the belief later arose that the carious process was associated, not so much with the consumption of large-moleculed carbohydrates such as starch, as with that of sucrose or other sugars. It followed from this theory that the most promising means of preventing caries would be to reduce the intake of sugar, to provide more of the fibrous foods which require vigorous mastication and thus minimize food stagnation in the mouth, and to ensure that the teeth were cleaned at short and regular intervals.

The Miller theory is still widely held by members of the dental profession in all parts of the world, but many workers in the field of dental research have come to believe that, whatever part sugar may play, there are other factors which must also have an important effect on the incidence of caries. Three significant factors in this concept are:

(1) The structure of the tooth (Mellanby, 1923, 1937; King, 1940).

(2) Conditions influencing the metabolism of the body, including that of the teeth after their development and eruption (Mellanby and Pattison, 1928; Boyd, Drain and Nelson, 1929; Committee for the Investigation of Dental Disease, Medical Research Council, 1936; McBeath and Zucker, 1938; Wynn, Haldi, Shaw and Sognnaes, 1953).

(3) Fluoride, as it affects either the chemical composition of the teeth or local conditions in the mouth (McKay, 1929; Ainsworth, 1933; Dean, Arnold and Elvove, 1942; Coumoulos, 1949; Dean, Arnold, Jay and Knutson, 1950).

In the investigation to be described here, the prime object was to see what relationship, if any, existed between dental caries in children and different levels of sugar intake in the diet. We were not directly concerned with the three factors mentioned above, as it was seen, when they were considered incidentally, that they could not materially affect the issue in this instance. When the investigation was planned the object was to ensure that, as far as possible, the only difference between the test and control groups was in their *dietary* intake of sugar, refined or unrefined.

* Dr. King died on November 22nd, 1952.

II. Plan of Investigation

In broad outline the suggested scheme comprised:

1. Observations of the incidence and spread of dental caries in groups of children in residential homes over a period of 1 year on their ordinary diet, in order to ascertain their 'natural' caries increase (1948 to 1949).

2. The addition of sugar, in the forms in which it is normally consumed, to the diets of some of the children for periods of 1, 1½ and 2 years, and a comparison of their dental condition at the end of these periods with that of control children on unsupplemented diets (beginning 1949).

Judged from a superficial point of view, the investigation may seem to be too simple in principle and to ignore many of the factors, environmental and otherwise, which might modify the effects on the teeth of an increased sugar consumption. It was simple in principle of deliberate choice, chiefly because large-scale investigations on human subjects, and particularly children, are administratively very difficult to conduct and the more complicated the approach the more likely is the investigation to fail.

During the time that the project was being discussed, the type of sugar supplement to be tested was considered. The work of Osborn, Noriskin and Staz (1937) had suggested that there was some factor in unrefined (raw) sugar which tended to protect the teeth from attack by caries and that this protective agent was removed when the sugar was purified. It was, therefore, decided to include the unrefined type of sugar in the diets of some of the test children and to give refined sugar to the others. Tests of several weeks' duration were made on a few children to see how the unrefined sugar was tolerated (Appendix II).

It was hoped that many parallel studies in different parts of the country might be undertaken, but owing to the difficulties involved, some of the schemes had to be abandoned. It was ultimately arranged that there should be three studies: one in the London area for which Lady Mellanby and Dr. J. D. King would be jointly responsible, one in Liverpool under the direction of Professor H. H. Stones, and one in Sheffield under the control of Professor H. N. Green.

For practical reasons, the choice of subjects for the investigation was restricted to children in residential homes (institutions), who took all or nearly all their meals there, since only under these conditions could adequate numbers, eating more or less controlled diets, be observed for any length of time.

The Committee originally intended to have three groups of children in each study: a control group consuming approximately the war-time (1939–45) level of sugar, and two groups, each consuming approximately the pre-war amount, one of refined and the other of unrefined sugar. They planned to ensure that the various groups were of about equal age and sex distribution, to standardize the observation periods, and, when necessary and as far as possible, to take into consideration the probable effects of the shedding of deciduous teeth and the eruption of permanent teeth during the period of investigation.

As is usually the case in clinical tests of this kind, not all of the original plans could be carried out. Many practical difficulties were encountered as was expected, the most intractable being the unavoidable departure of some children from the various institutions before the final inspections. The plan to observe the 'natural' increase in caries before changes were made in the sugar content of the diet had to be altered, tests with unrefined sugar were ultimately confined to the London children (and then only in a modified way), and in Sheffield none of the children continued with the sugar supplement for longer than 18 months.

It was not an easy matter to find sufficient numbers of children suitable for the tests in any of the three centres, but perhaps the hardest task was in the London area where the teeth of very young children were to be observed. Largely owing to the evacuation of the big residential homes during the war and the consequent splitting up of large communities into smaller groups in country houses where they had since remained, there appeared to be no single home in or near London suitable for a large-scale study. Recourse had, therefore, to be made to a number of scattered smaller homes,* twenty-one in all, and this added greatly to the amount of organization and work involved. In the Liverpool district a large home, housing under one roof sufficient children for the purposes of the study, was selected, while in Sheffield an institution run on the 'cottage homes' principle, each cottage housing about fourteen children of various ages under the care of a foster-mother, was available.

At the beginning of the inquiry, the children taking part in the London study were all 2 to 4 years of age, and their teeth were, therefore, all deciduous. The children were older and the age-range was greater in Liverpool and Sheffield, namely from 4 to 14 years at the beginning of the investigation, so that the results for these two centres concern the effects of the supplements on both deciduous and permanent teeth. It was realized, of course, that in the intermediate age-groups in particular, assessment of caries incidence was complicated by the shedding of the deciduous and the eruption of the permanent teeth, but the decision to include children of this age was dictated by the difficulty of otherwise obtaining sufficient numbers. For these reasons, the Liverpool and Sheffield results were confined, as far as publication was concerned, to deciduous first and second molars as one group and permanent first molars as the other, although the condition of all teeth present at the time of inspection was recorded.

III. General Notes on the three Studies

DIET

Basal Diet

Since the purpose of the investigation was to find the effect on the incidence and spread of caries in children's teeth of varying the amount of sugar in their diets, it was considered advisable that, before any alterations were made, the children's normal, or basal, diets should be assessed in order to see whether they could be considered good by known standards, how they compared in the different centres, and what the average sugar consumption was.

The investigation took place at a time when there was, and had been for some years, compulsory rationing of many staple foods. In all three centres it was found that a balanced and adequate diet was secured by giving the children their full rations of meat, fats and cheese, a liberal allowance of milk, and regular servings of fresh fruit and vegetables. In addition, all the children in London and Sheffield, and the younger ones in Liverpool, had supplements of cod-liver oil and orange juice.

It was not part of the plan to keep continuous records of the exact quantities of any of the foods consumed by the children under observation, except as far as possible in the case of sugar, but occasional checks were made by the dietitians assisting with the investigation to see how much food was actually eaten, and

* For convenience, these will be referred to collectively as 'the London homes'.

these checks confirmed that the children were getting enough calories, protein, mineral salts and vitamins, according to recognized standards.

Further details of the approximate composition of the diets will be found in later sections of the Report dealing separately with the three centres.

Sugar

It was comparatively easy to weigh and measure the amount of sugar as such used in the homes for cooking and for sweetening dishes at the table, but not possible to determine at all accurately the amounts eaten in the form of jam, syrup, honey and sweets (candies). It was, however, assumed for the purpose of rough calculation that jam contained 60 per cent by weight of sugar, honey and syrup 75 per cent, and that the over-all figure of 65 per cent represented the sugar content of all preserves in these diets. It was further assumed that the sweets eaten by the children had on the average a sugar content of 90 per cent. (In this connexion see p. 14 for an alteration made in the case of the control group at the beginning of the London investigation.)

On this assessment the children's diets contained considerable amounts of sugar prior to the investigation. The consumption in the London homes ranged from 12½ to 23 oz. per child per week; in Liverpool it averaged 15 oz. per week, and in Sheffield 19½ oz. in winter and 23½ oz. in summer.

For the period of the investigation it was decided to add 22 oz. of refined white sugar per child per week to the diets of the test groups in Liverpool and Sheffield, as it was calculated that this amount would bring the total sugar consumption up to something like the estimated pre-war level. The total amounts of sugar actually obtained from all sources by these children, both boys and girls, ranging in age from 4 to 14 years at the first inspection, were 37 oz. per week in Liverpool and 41½ oz. (45½ oz. in the summer months) in Sheffield. The control group in each of these two centres had no additional sugar. In this connexion it is of interest to note that Widdowson (1947), in observations made during the years 1935 to 1939 on individual children, showed that the total average weekly consumption of sugar from all sources rose from approximately 15 oz. at the age of 4 years to a peak of 38 oz. at 15 in the case of boys, while for girls the figures were 17 oz. at 4 years, rising to a peak of 26 oz. at 14 and then falling slightly (Table 1).

TABLE 1

Estimated average weekly amounts of sugar from all sources consumed by boys and girls during 1935–39 (*Widdowson*, 1947)

	Age (years)														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Sugar per week (oz.)														
Boys	13	15	15	16	17	22	21	25	25	25	29	29	34	38	33
Girls	13	12	17	14	17	18	22	21	23	22	21	23	26	23	21

In the London homes it was considered impossible to get all the children, who were only 2 to 4 years old at the beginning of the investigation, to eat for long periods anything approaching 22 oz. of sugar per week over and above their usual amount. It was therefore arranged that the children in the control

group should receive about 11 oz. per week, which was rather less than their usual amount, so that the test children, of whom there were two groups, one on white and one on brown sugar, could be given without difficulty about twice the amount which the control children received, that is to say approximately 22 oz. of total sugar. Widdowson's figures (Table 1) for children of the same age-group ranged from 13 to 15 oz. per week for boys and 13 to 17 oz. for girls, so that, on this basis, the diets of the test subjects in the London study probably contained more total sugar than would have been consumed by such young children before the war.

Administration of sugar. This naturally varied at the different centres and in the individual homes. Such details as are available in this connexion are included in the separate sections dealing with London, Liverpool and Sheffield.

DENTAL EXAMINATIONS

At each centre all the dental examinations were carried out by the same member or members of the particular team of investigators, all of whom had good experience of this type of examination.

The criteria and procedures were similar in all groups. However, in the London study two types of chart were used, whereas only one, differing in each case, was employed in Liverpool and Sheffield.

Name..... Age..... No.....

Address..... Date.....

Mottling (1, 2, 3, 4, 5, 6)												
M-hypoplasia (1, 2, 3) & G												
Caries (1, 2, 3)												
Teeth present		e	d	c	b	a	a	b	c	d	e	
Teeth present		e	d	c	b	a	a	b	c	d	e	
Caries (1, 2, 3)												
M-hypoplasia (1, 2, 3) & G												
Mottling (1, 2, 3, 4, 5, 6)												

State of mouth..... Occlusion.....

..... Attrition.....

Tartar..... Stain.....

Gingivitis..... Mottling.....

Other notes:

FIG. 1. Dental chart used in London study for all children.

If no caries or fillings were seen in the mouth of a child in a London home, then a small chart only was used (Fig. 1), similar to that previously employed in many static surveys (Mellanby and Coumoulos, 1946). On this chart the dental and oral condition was recorded numerically. If, on the other hand, any carious lesion, filled or untreated, was observed at the first or any subsequent inspection, a larger chart containing diagrams of all tooth surfaces was

also used (Fig. 2), so that the position and extent of the lesion could be indicated graphically. In order that the examiner should not be biassed by previous records, new blank charts were used for the third inspection. These were then compared with the previous charting, and if there were any doubtful entries they were reconsidered before the new details were transferred to the original charts. Increase in the size of carious areas from one inspection to another was shown by the use of a different coloured pencil on each occasion. Charts of this latter type had also been used earlier for examinations repeated several times, notably in previous Sheffield (Mellanby and Pattison, 1928) and Birmingham (Committee for the Investigation of Dental Disease, 1936) investigations.

The Liverpool and Sheffield investigators in the present study used only one chart (Fig. 3 for Liverpool, Fig. 4 for Sheffield) on which were recorded the teeth present, the position, degree of and increase in caries of individual teeth. the extent of fillings, the position and severity of gingival inflammations and the position and amount of calculus deposits. The position of a cavity or filling was indicated by appropriate letters and the severity of any condition was rated numerically. The Liverpool chart contained in addition provision for the results of certain chemical and bacteriological investigations. A new chart was used for each examination and the findings of the previous examination were not available to the examiner until he had completed his assessment. Then any questionable lesions reported on the previous chart were re-examined and their presence confirmed or otherwise.

In all cases, the dental examinations, which were carried out at six-monthly intervals, were made under good illumination with a mouth mirror and sharp probe. The probes were frequently renewed.

In all three studies a tooth was considered to be erupted when the whole of the occlusal surface was through the gum.

For both dentitions the criteria of caries were as follows:

C_0 No caries: no 'catching' of examiner's probe.

C_1 Slight caries: very small cavities; pits and fissures suspected of caries on account of the probe 'catching', and indefinite but strongly suspected approximal lesions.

C_2 Moderate caries: definite cavities penetrating through the enamel to the dentine and involving up to one fourth of the tooth crown, including undermining lesions.

C_3 Advanced caries: cavities involving destruction of more than one fourth of the crown. Included in this grade were, of course, any teeth of which only the carious roots remained.

All filled teeth were charted as carious and graded as such, according to the estimated extent of the lesion.

ASSESSMENT OF RESULTS

The main findings have been expressed in terms of:

1. *Freedom from caries*

In London—percentage of caries-free deciduous dentitions.

In Liverpool and Sheffield—percentage of dentitions with:

(i) caries-free deciduous molars

(ii) caries-free permanent first molars.

2. *Incidence and extent of caries*
   (a) percentage of carious teeth
   (b) average caries figure (A.C.F., see below)
   (c) increase in A.C.F.
   (d) percentage of initially non-carious teeth which developed caries during the investigation

   In London—deciduous teeth of all types.

   In Liverpool and Sheffield—
   (i) all deciduous molars
   (ii) permanent first molars.

The average caries figure (A.C.F.) is the sum of the caries-grade figures ivided by the total number of teeth observed, including those extracted for aries; but, as will be seen below, the system of quoting the total number of teeth iffers in London from that used in Liverpool and Sheffield. The increase in .C.F. measures the spread of original lesions and the initiation of new ones uring the period of observation.

In assessing freedom from caries and the incidence and extent of this ondition, somewhat different standards were used in London from those dopted in Liverpool and Sheffield. This was largely due to the fact that all the hildren in the London homes were under 5 years of age at the beginning of he investigation and only the deciduous teeth were involved, whereas in the ther two surveys the age-range was much wider—from 4 to 14 years initially—nd there were both deciduous and permanent teeth, complicated by the rocesses of shedding and eruption, to be considered.

The London results were based on *all* the deciduous teeth of the children, xcept the few incisors which had been shed by the older children prior to the nvestigation and the few molars which were unerupted in the younger children t the first inspection and were ignored even though found to be erupted at ater inspections. When estimating the percentage of caries-free children, the ercentage of carious teeth and the average caries figure (A.C.F.), account was aken not only of the teeth present at the time of any inspection, but also of vidence of past caries. Thus, missing deciduous canines and molars, which were ew in number, known (or if not known at the first inspection, assumed because f the age of the children) to have been extracted for caries, were considered, or the purposes of these estimations, to have the most severe grade of the isease (C_3). Carious teeth present at the first inspection but subsequently shed ere assumed to have the same degree of caries as at the last inspection at hich they were present.

The Liverpool and Sheffield results, on the other hand, were based only on eciduous first and second molars and permanent first molars, because of the omplications mentioned above. Moreover, the figures obtained were calcu-ted only on teeth actually present at the first inspection. Teeth missing at the rst examination were not included in the results, and teeth which erupted uring the investigation were also excluded. Molars present at the first inspection nd subsequently known or presumed to have been extracted for advanced aries were ranked as grade C_3 in assessing the results.

The percentages of children with caries-free molars, the percentages of carious olars, and the average caries figures for the Liverpool and Sheffield studies n deciduous teeth (Tables 12, 16 and 18) cannot therefore be compared with milar figures for the molars of the London children.

NUTRITION BUILDING, NA

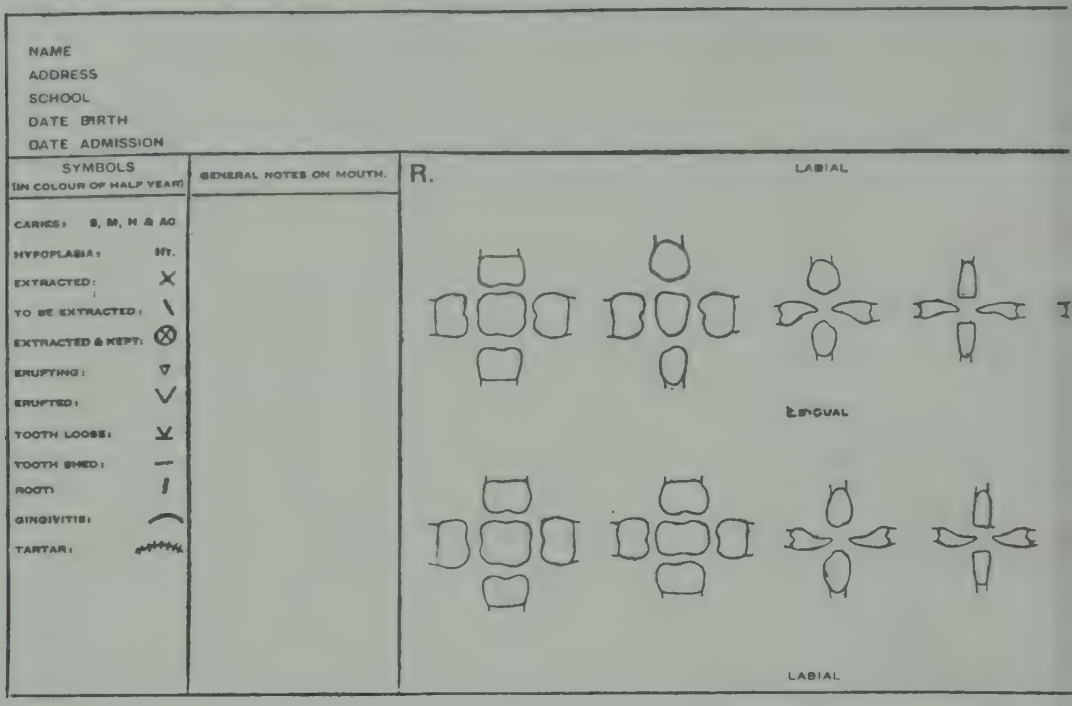


FIG. 2. Dental chart used i

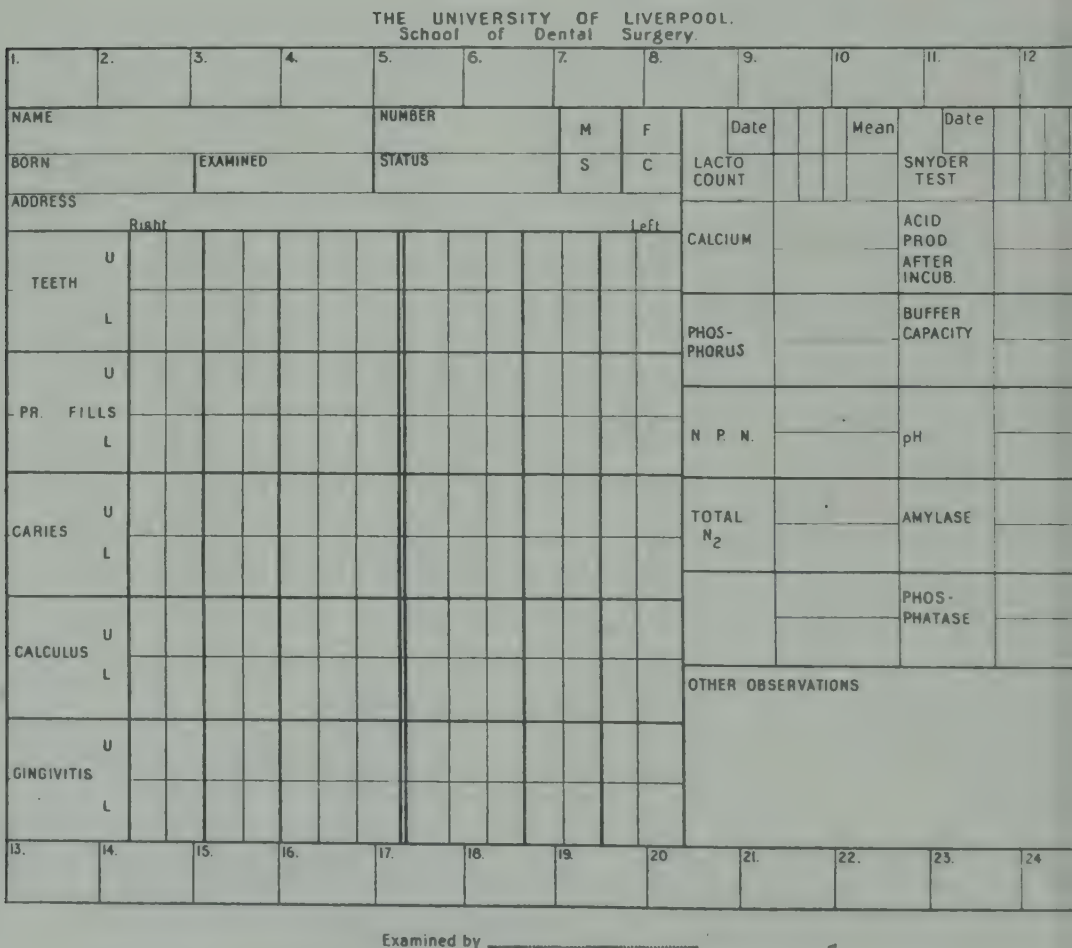


FIG. 3. Dental chart used in Liverpool study.

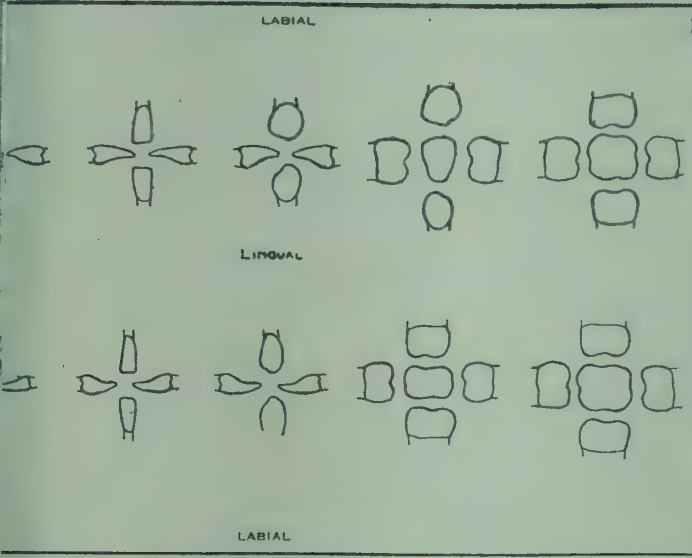
FOR MEDICAL RESEARCH

INSPECTION

DIET

PESTION

DURATION INVESTIGATION



ARCH AND PALATE.

ALIGNMENT AND SPACING.

OCCLUSION.

ADENOIDS.

GUM.

TARTAR.

FILM.

ATTRITION.

HYPOPLASIA.

CARIES.

NOTES.

or children with carious teeth.

THE UNIVERSITY OF SHEFFIELD.
School of Dental Surgery.

NAME

BORN

ADDRESS

DATE FIRST EXAMINED

OTHER OBSERVATIONS

Right Left

TEETH U L

FILLS U L

CARIES U L

CALCULUS U L

GINGIVITIS U L

G-HYPOPLASIA U L

M-HYPOPLASIA

ORAL HYGIENE

NOTES

Examined by .....

FIG. 4. Dental chart used in Sheffield study.

It will be seen in Tables 6 to 9, 12, 13, and 16 to 19 that the differences between certain figures are said to be statistically significant. The 5 per cent level of significance has been used throughout; that is to say, a difference which is equal to or greater than twice its standard error has been taken as being greater than would be expected from random fluctuations.

The standard errors used throughout this Report are based on differences between children treated alike. This simple method of calculation results in some over-estimate of the standard errors for Liverpool, where the children were paired, but where, owing to the withdrawal of children, not all pairs were complete. For London and Sheffield, on the other hand, where whole homes or cottages were treated alike, the simple method somewhat understates the standard errors. However, as so few results are significant and where they are significant they are not consistently so in the same direction, the conclusions drawn cannot be affected by the employment of the simple method.

OTHER OBSERVATIONS

In the London study observations were made on the structure of the teeth, the length of time the children had been in the homes and their average age at the beginning of the investigation. Reference is made to these on p. 21.

In Liverpool, bacteriological and biochemical investigations of the saliva were undertaken. The bacteriological investigation was to determine whether increased sugar in the diet might produce some changes in the micro-organisms contained in the saliva of children in the sugar group when compared with the control group. Two bacteriological tests were used, one to count the number of lactobacilli per ml. of saliva (Hadley, 1933), the other to measure the rate of acid production of whole saliva (Snyder, 1940). Saliva specimens were collected and tests were carried out at the beginning, during and at the end of the investigation. In the biochemical investigation it was decided to study the buffering capacity of the saliva in a number of girls from the sugar and control groups. These tests are recorded in Appendix I, p. 45.

IV. Methods and Results of the Individual Studies

A. London

HOMES AND CHILDREN

As was mentioned earlier, the main plan of this part of the investigation was to compare, at six-monthly intervals, the spread of existing caries and the initiation of new lesions in three groups of young children in residential homes whose diets varied only in their sugar content. One group was to have a diet with relatively little sugar, representing approximately the war-time consumption for the given ages, the second group a higher intake of white (refined) sugar so that the total amount eaten corresponded roughly to the pre-war level, and the third an intake equal in quantity to that of the second group, but of brown (unrefined) sugar, referred to by the trade as 'raw'.

It must be emphasized that it was planned to use in this London study only children of 2 to 4 years of age (i.e. up to but not including the fifth birthday) at the beginning of the observation period, since earlier investigations in Sheffield and Birmingham, referred to on p. 6, had shown the many difficulties

which arose from the inclusion of older children whose deciduous teeth, which had been exposed for longer periods to carious attack, were being shed and whose permanent teeth were erupting during the period of observation.

As there appeared to be no large home in or near London where the whole of this study could be carried out, approaches were made to various authorities responsible for administering children's homes in London and within a radius of about sixty miles, with a view to finding a number of smaller centres suitable for the tests. As a result, four local authorities and a number of independent religious organizations agreed to take part in the scheme if their homes were considered suitable. Twenty-seven of these homes were visited and the children were dentally examined; twenty-three homes were finally chosen for the study. The outline of the scheme was explained to the respective principals, all of whom expressed their willingness to co-operate to the fullest extent possible. This voluntary participation was important, indeed essential, as the success of the work depended on their interest and help.

Grouping of Children

Though the homes differed to some extent in the number of children they housed and in the conditions under which they were run, an attempt was made to divide them into three groups which would be as comparable as possible in all respects. Seven homes were allocated to the control group, and eight to each of the other two groups, the numbers of children in the three groups being approximately the same. Unfortunately, however, two homes in the control group were withdrawn from the scheme before the end of the first year, leaving only five in this group and twenty-one in all. There were also the expected and unavoidable losses of individual children from all groups during the course of the study, owing to their return to parents or other relatives, adoption, or transfer to other homes. The numbers observed over periods of 1, 1½ and 2 years in the three groups were as follows:

Group	1 *year*	1½ *years*	2 *years*
Control	126	69	30
Sugar:			
White (refined) ..	151	90	32
Brown (unrefined) ..	114	65	20
Totals	391	224	82

DISTRIBUTION OF CARIES IN HOMES PRIOR TO INVESTIGATION

As previously stated, it was the intention of the Dental Research Committee that, before the sugar tests were begun, the 'natural' increase in caries over a period of 1 year should be ascertained in the homes co-operating in the investigation. In the London area a few children (54) aged 2½ to 5 years were examined in the spring of 1948 and again a year later. At the beginning of the observation period only 1·5 per cent of all the teeth of these children were carious and after a year this figure had risen to 2·9 per cent. The average caries figure rose from 0·02 to 0·04 in the same time.

The amount of caries in all the residential homes taking part in the London study is shown in Tables 2 and 3. Among 678 children ranging in age from 2

to 5 years whose teeth were charted in 1949 before the diet alterations were made, 1·0 per cent of the teeth of the 2-year-olds were carious and there was a slight increase in each succeeding age-group, culminating in 6·2 per cent carious among the 5-year-old children. The over-all figure was 3·2 per cent. When the individual types of teeth of all the children together, irrespective of age, were considered, it was found that the lower molars had the most caries and that the upper central incisors had only slightly less; but in no case did the percentage of carious teeth exceed 9·8 (including the few teeth that had been extracted because of disease) nor did the A.C.F. exceed 0·15.

Teeth-cleaning habits varied among these young children. In some cases the teeth were not brushed at all, but in others they were cleaned once or twice a day, either by the children themselves, or by the staff of the homes.

TABLE 2

London study: age distribution of caries in 678 *children aged* 2 *to* 5 *years examined in* 1949

Age-group (years)	No. of children	Percentage of teeth carious	Average caries figure
2	138	1·0	0·01
3	243	2·7	0·04
4	222	4·2	0·07
5	75	6·2	0·10
2–5	678	3·2	0·05

TABLE 3

London study: distribution of caries in the different types of teeth of 678 *children aged* 2 *to* 5 *years examined in* 1949*

Teeth	Percentage of teeth carious	Average caries figure
Upper jaw:		
1st incisors ..	6·2	0·10
2nd incisors ..	3·0	0·05
Canines	0·1	0·00
1st molars ..	3·2	0·05
2nd molars ..	4·1	0·07
Lower jaw:		
1st incisors ..	0·2	0·00
2nd incisors ..	0·1	0·00
Canines	0·1	0·00
1st molars ..	5·7	0·10
2nd molars ..	9·8	0·15
Total for both jaws	3·2	0·05

* Same children as in Table 2.

DIETS BEFORE AND DURING INVESTIGATION

As each home was brought into the scheme the general make-up of the diets, with particular reference to the children's current intake of sugar from all sources, was investigated. It was found that much guidance regarding feeding was already given to the superintendents or matrons of most homes by the authorities responsible for their administration. This consisted of general advice on rationing problems, on weekly menus and on suitable recipes. All the homes kept diet books and, with certain seasonal variations, appeared to adhere to the menus suggested.

Basal Diets and Dietary Checks

The basal diets (Table 4) were above the average in nutritional qualities for children of the 'ordinary domestic consumer' class. All meals were taken in the homes, and not only did the matrons purchase the full ordinary quantities of rationed foods, but the majority availed themselves of the additional nursery rations which could be had by orphanages and similar institutions in lieu of nursery school meals (Ministry of Food, 1951). By this means most of the children obtained an additional $\frac{1}{3}$ pint of milk per day, making a total average consumption of nearly $1\frac{1}{2}$ pints daily, and sufficient extra amounts of rationed foods, such as meat, fats, cheese and eggs, for five main meals a week on the scale allowed for school meals. Some dried milk and occasionally some dried egg was used in cooking, and daily doses of cod-liver oil and concentrated orange juice were given. All the children had as much bread as they asked for, most of which was made from flour of the high-extraction (85 to 80 per cent) National type, with its added calcium carbonate. Potatoes were served every

TABLE 4

London study: approximate average consumption per head of main foods, excluding sugar

Milk, fresh	10–10½ pints a week
Milk, dried and tinned	Some used in cooking
Eggs, fresh	3–3½ a week
Eggs, dried	Occasionally
Cheese, Fats, Meat and bacon	Full rations plus extra nursery rations in most cases
Unrationed meat and offal (liver, kidneys etc.)	About once a week
Fish	Once or twice a week
Bread (usually 'National' white)	Ad lib.
Cereals, including cornflakes, porridge and rice	About once a day
Potatoes	Ad lib. every day
Green and root vegetables	About once a day
Fresh fruit	4–8 times a week
Cod-liver oil, Orange juice	Daily (in doses recommended by the Ministry of Food)

day, fresh vegetables most days, and fresh fruit from four to eight times a week, depending on the season and the availability of home-grown produce.

Occasional checks were made over periods of one to six days on the amounts of food eaten by sample groups in the various homes. These confirmed the view that the diets were providing adequate amounts of calories, protein, calcium, iron and water-soluble and fat-soluble vitamins. It seemed clear, therefore, that there was ample food of good nutritional quality available to satisfy all appetites and most physiological needs.

Sugar

As previously stated in the Introduction, it was originally intended that the low sugar intake should represent the approximate war-time consumption, and the higher intake the pre-war level; the latter, according to the Report of Widdowson (1947) already quoted, ranged from 13·3 to 16·6 oz. a week for boys and girls aged 2 to 4 years and up to 17·4 oz. for children of both sexes aged 6 years. The sugar intake was estimated in all homes before the tests began. In some, where the matron herself allocated certain amounts to the kitchen for cooking and to the nurseries for addition to various foods at table, the matter was relatively simple. In a few, where the nurseries received part of their food from a main kitchen but had breakfasts, teas and mid-morning snacks from a kitchenette attached to the nursery building, estimation of the sugar consumption was more complicated; in such cases the dietitian weighed samples of prepared dishes and calculated the sugar content from the recipes. Before the investigation the total sugar intake in the different homes varied and was, on the whole, higher than had been anticipated, partly owing to the extra amounts of rationed food, including sugar, obtained in lieu of school meals at most of the homes (see p. 13). On the other hand, some homes with a substantial proportion of bottle-fed babies found that the milk mixtures absorbed an undue proportion of sugar, so that there was less available for the older children. The largest single factor affecting the sugar levels before the test was begun was the quantity of preserves eaten, which varied from 2 to 10½ oz. per child per week in the different homes. Later, during the investigation, the consumption of preserves was stabilized (see Table 5).

During the investigation period the approximate average weekly consumption of sugar per child in the three groups was as follows:

1. *Control group*: 11 *oz.* This figure was achieved mainly by limiting the quantity of jam, syrup and honey, and by providing sweets (chiefly chocolate, gums and jellies) with a lower sugar content than those supplied to the other groups. The amount of sugar in these sweets was estimated at 62½ per cent, as compared with 90 per cent in the sweets eaten by the white and brown sugar groups. In some cases a slight reduction was also made in the amount of sugar used for cooking and at table.

2. *White sugar group*: *just over* 22 *oz.* All sugar eaten as such (i.e. apart from that in preserves and sweets) by this group was of the white, or refined variety. Any extra given in addition to that previously consumed was usually taken with cereals, stewed fruit, puddings and drinks. A small amount was sometimes spread on bread and butter.

3. *Brown sugar group*: *about* 21½ *oz.* Owing to a misunderstanding, demerara (i.e. semi-refined) sugar was given in place of some of the raw sugar, and in a few of the homes up to 2 oz. of white sugar per child per week was used for cooking. Any sugar in excess of the amount previously eaten was used in the same ways as by the white sugar group.

TABLE 5

London study: approximate average weekly sugar consumption per child

Source of sugar	Control group		White sugar group		Brown sugar group	
	Amount consumed (oz.)	Estimated sugar content* (oz.)	Amount consumed (oz.)	Estimated sugar content* (oz.)	Amount consumed (oz.)	Estimated sugar content* (oz.)
Sugar, as such ..	6	6	14	14	13¼	13¼
Jam, syrup, honey	4	2½	6¾	4½	6¾	4½
Chocolate, sweets ..	4	2½	4¼	3¾	4¼	3¾
Total	14	11	25	22¼	24¼	21½

* Refer to text (pp. 4 and 14) for method of arriving at these figures.

Each home made its own arrangements for giving chocolate and sweets to the children. Sometimes they were given as part of a meal, sometimes immediately after, and sometimes between meals or even at bedtime.

DENTAL CARIES RESULTS

The caries experience of each of the three groups of London children for all types of teeth together has been analysed by age (one-year divisions) and by length of observation in the inquiry, and figures are also given to show the findings for different types of teeth in children aged 2 to 4 years combined.

Table 6 gives the numbers of children seen over periods of 1, 1½ and 2 years, and the proportion with no carious teeth in each group and sub-group at the beginning and end of the study. The incidence, extent and spread of caries in all types of teeth together at these times are shown in Table 7. The findings are expressed as the percentage of carious teeth (equivalent to the d.e.f.—decayed, extracted and filled—figure per 100 teeth), the A.C.F. (average caries figure), the increase in the A.C.F. (which covers the spread of former caries and the initiation of new lesions), and the percentage of previously non-carious teeth which developed caries during the period under review.

One-year Study

The numbers of children studied for at least one year were 126 in the control, 151 in the white sugar and 114 in the brown sugar group. The proportions with no carious teeth at the first inspection were very similar in the three groups for all ages combined, and at the end of the year, though lower than

TABLE 6

London study: caries-free children aged 2 to 4 years

Age at beginning of study (years)	No. of children			Percentage of children caries-free						Decrease in percentage of caries-free children		
				Beginning of period			End of period					
	C*	W	B	C	W	B	C	W	B	C	W	B
	Studied for 1 year											
2	49	53	45	89·8	100·0	93·3	73·5	75·5	71·1	16·3	24·5	22·2
3	59	68	46	84·7	79·4	76·1	54·2	57·4	47·8	30·5	22·0	28·3
4	18	30	23	77·8	76·7	73·9	50·0	43·3	52·2	27·8	33·4	21·7
2–4 inclusive	126	151	114	85·7	86·1	82·5	61·1	60·9	57·9	24·6	25·2	24·6
	Studied for 1½ years											
2	31	30	22	83·9	100·0	86·4	61·3	83·3	54·5	22·6	16·7	31·9
3	31	48	31	87·1	81·2	80·6	51·6	45·8	45·2	35·5	35·4	35·4
4	7	12	12	100·0	83·3	75·0	57·1	41·7	33·3	42·9	41·6	41·7
2–4 inclusive	69	90	65	87·0	87·8	81·5	56·5	57·8	46·2	30·5	30·0	35·3
	Studied for 2 years											
2	16	15	3	93·8	100·0	66·7	37·5	93·3	33·3	56·3	6·7	33·4
3	11	14	8	90·9	71·4	87·5	18·2	28·6	25·0	72·7	42·8	62·5
4	3	3	9	100·0	66·7	88·9	0·0	66·7	22·2	100·0	0·0	66·7
2–4 inclusive	30	32	20	93·3	84·4	85·0	26·7	62·5	25·0	66·6	21·9†	60·0

* C = control group; W = white sugar group; B = brown sugar group.

† The value for the white sugar group is significantly below those for the control and brown sugar groups.

at the outset, they were again approximately equal. As might be expected, the general trend was for the percentage of caries-free children to be greatest among the 2-year-olds and to decline with increasing age. Only small differences between the three groups were found in the percentages of carious teeth (d.e.f.) and the A.C.F. at the beginning and at the end of the year. The over-all increase in A.C.F. was similar in each of the groups and showed a rise with age within each group. The incidence of caries developing during the year in teeth previously caries-free followed the same trend as the A.C.F.

One-and-a-half-year Study

The numbers of children remaining in the investigation for 1½ years were 69 in the control, 90 in the white sugar and 65 in the brown sugar group. A decrease in the proportion of caries-free subjects with increasing age, which was a feature of the children observed for 1 year, was not shown by each group in this part of the inquiry, probably because of the smaller numbers in some of the individual 1-year age divisions. At the first inspection the percentage of children of all ages in the three groups who were caries-free was not

Age at beginning of study (years)	Number of teeth			Percentage of teeth carious (d.e.f.)						Average caries figure						Increase in average caries figure			Percentage of non-carious teeth which developed caries during period		
				Beginning of period			End of period			Beginning of period			End of period								
	C*	W	B	C	W	B	C	W	B	C	W	B	C	W	B	C	W	B	C	W	B
										Studied for 1 year											
2	939	984	868	1·0	0·0	0·5	3·0	2·6	3·8	0·011	0·0	0·006	0·040	0·034	0·048	0·029	0·034	0·042	2·0	2·6	3·4
3	1,177	1,359	912	1·7	2·4	1·9	6·1	6·8	6·3	0·024	0·035	0·025	0·084	0·095	0·084	0·060	0·060	0·059	4·5	4·5	4·5
4	360	598	458	2·8	5·7	2·6	9·7	11·4	6·1	0·028	0·095	0·035	0·122	0·197	0·096	0·094	0·102	0·061	7·1	6·0	3·6
2–4 inclusive	2,476	2,941	2,238	1·6	2·3	1·5	5·5	6·4	5·3	0·019	0·035	0·020	0·073	0·095	0·073	0·054 ±0·005	0·060 ±0·005	0·053 ± 0·006	3·9	4·2	3·9
										Studied for 1½ years											
2	598	551	425	1·5	0·0	0·9	5·0	1·5	6·4	0·018	0·0	0·012	0·077	0·016	0·089	0·059	0·016	0·077	3·6	1·5	5·5
3	618	959	616	1·5	2·1	1·5	7·9	8·0	6·8	0·021	0·029	0·021	0·131	0·112	0·107	0·110	0·083	0·086	6·6	6·1	5·4
4	140	240	240	0·0	2·1	2·9	4·3	8·3	8·3	0·0	0·021	0·038	0·064	0·104	0·146	0·064	0·083	0·108	4·3	6·4	5·6
2–4 inclusive	1,356	1,750	1,281	1·3	1·4	1·6	6·3	6·0	6·9	0·018	0·019	0·021	0·100	0·081	0·109	0·082 ±0·010	0·062 ±0·007	0·088 ±0·011	5·0	4·6	5·5
										Studied for 2 years											
2	316	268	60	0·3	0·0	1·7	7·0	0·7	8·3	0·006	0·0	0·017	0·089	0·007	0·100	0·083	0·007†	0·083	6·7	0·7†	6·8
3	219	279	159	0·5	3·9	1·3	11·0	11·8	10·7	0·009	0·057	0·013	0·192	0·179	0·145	0·183	0·122	0·132	10·6	8·2	9·6
4	60	60	180	0·0	6·7	1·1	13·3	10·0	8·3	0·0	0·067	0·011	0·183	0·200	0·122	0·183	0·133	0·111	13·3	3·6	7·3
2–4 inclusive	595	607	399	0·3	2·5	1·3	9·1	6·8	9·3	0·007	0·033	0·013	0·136	0·105	0·128	0·129 ±0·019	0·072‡ ±0·012	0·115 ±0·020	8·8	4·4†	8·1

* C = control group; W = white sugar group; B = brown sugar group.

† The value for the white sugar group is significantly smaller (see p. 19) than the values for the controls and the brown sugar group.

‡ The value for the white sugar group is significantly smaller than that for the controls but not than that for the brown sugar group.

TABLE 8

London study: incidence, extent and spread of caries in different types of teeth in children aged 2 to 4 years

Types of teeth	Number of teeth			Percentage of teeth carious						Average caries figure						Increase in average caries figure			Percentage of non-carious teeth which developed caries during period		
				Beginning of period			End of period			Beginning of period			End of period								
	C*	W	B	C	W	B	C	W	B	C	W	B	C	W	B	C	W	B	C	W	B
Studied for 1 year																					
1st incisors	501	601	450	2·2	2·0	2·9	5·2	3·7	6·4	0·024	0·027	0·042	0·064	0·057	0·089	0·040	0·030	0·047	3·1	1·7	3·7
2nd incisors	504	604	452	1·4	0·7	0·7	2·6	1·8	1·3	0·016	0·010	0·007	0·036	0·031	0·015	0·020	0·022	0·009	1·2	1·2	0·6
Canines	504	594	454	0·0	0·7	0·0	0·0	0·7	0·0	0·0	0·017	0·0	0·0	0·017	0·0	0·0	0·0	0·0	0·0	0·0	0·0
1st molars	504	604	456	1·2	4·1	1·3	3·0	7·3	3·9	0·012	0·068	0·018	0·040	0·126	0·061	0·028	0·058	0·044	1·8	3·3	2·7
2nd molars	463	538	426	3·2	4·1	2·6	17·5	19·7	15·3	0·048	0·058	0·033	0·240	0·262	0·207	0·192	0·204	0·174	14·7	16·3	13·0
Studied for 1½ years																					
1st incisors	274	360	258	1·1	1·1	3·5	4·4	3·9	7·8	0·011	0·011	0·054	0·069	0·042	0·116	0·058	0·031	0·062	3·3	2·8	4·4
2nd incisors	276	360	258	2·2	0·0	0·8	3·3	0·8	1·6	0·025	0·0	0·008	0·047	0·008	0·019	0·022	0·008	0·012	1·1	0·8	0·8
Canines	276	352	260	0·0	0·0	0·0	0·4	0·0	0·4	0·0	0·0	0·0	0·004	0·0	0·004	0·004	0·0	0·004	0·4	0·0	0·3
1st molars	276	360	259	1·1	3·1	0·4	4·7	5·8	3·9	0·011	0·039	0·004	0·080	0·092	0·066	0·069	0·053	0·062	3·7	2·9	3·5
2nd molars	254	318	246	2·4	3·1	3·3	19·6	21·1	22·0	0·044	0·047	0·041	0·319	0·286	0·350	0·276	0·239	0·309	17·7	18·5	19·3
Studied for 2 years																					
1st incisors	119	128	79	0·0	3·1	2·5	5·0	6·3	11·4	0·0	0·031	0·025	0·059	0·086	0·165	0·059	0·055	0·139	5·0	3·2	9·1
2nd incisors	120	128	80	0·8	0·0	0·0	0·8	0·0	2·5	0·017	0·0	0·0	0·017	0·0	0·025	0·0	0·0	0·025	0·0	0·0	2·5
Canines	120	120	80	0·0	0·0	0·0	0·8	0·0	0·0	0·0	0·0	0·0	0·008	0·0	0·0	0·008	0·0	0·0	0·8	0·0	0·0
1st molars	120	128	80	0·0	5·5	1·3	5·0	9·4	10·0	0·0	0·078	0·013	0·083	0·172	0·138	0·083	0·094	0·125	5·0	4·1	8·9
2nd molars	116	103	80	0·9	3·9	2·5	34·5	20·3	22·5	0·017	0·058	0·025	0·526	0·301	0·313	0·509	0·243†	0·288†	33·9	17·2†	20·5†

* C = control group; W = white sugar group; B = brown sugar group.

† The values for the white and brown sugar groups are significantly smaller than the value for the controls.

significantly different, varying only between 87·8 and 81·5; at the end of 1½ years, although the figures for the control and white sugar groups were in effect the same, 56·5 and 57·8 per cent respectively, in the brown sugar group only 46·2 per cent were free from the disease; however, the differences between the groups were not significant. The percentages of carious teeth (d.e.f.) and the A.C.F. at the beginning and end of the eighteen months' observation period were, for all ages combined, practically the same, but small fluctuations in the trends occurred between the groups at different ages, probably because of the small numbers of children on which some of the values were based. The increase in the A.C.F. during the period was, for all ages combined, essentially the same for the control and brown sugar groups, but less, though not quite significantly so, for the white sugar group, while the percentage of caries-free teeth which developed caries during the period was very similar for the three groups. No regular progression in caries incidence with age was apparent.

Two-year Study

The numbers of children who remained under observation for 2 years were only 30 in the control, 32 in the white sugar and 20 in the brown sugar group. When they were divided into 1-year age-groups the numbers in each were very small, especially those in the 4-year-old groups, so that their individual results are not of great value; they are, however, given in the tables. For the three age-groups combined the percentages of caries-free children in the control and sugar groups at the first inspection did not differ appreciably, ranging from 84·4 to 93·3, but, at the end of 2 years, only 26·7 and 25·0 per cent respectively of the children in the control and brown sugar groups were free from caries compared with 62·5 per cent in the white sugar group, a statistically significant difference. This white sugar group had a slightly higher initial percentage of carious teeth (d.e.f.) and A.C.F. than the other two groups, but at the end of 2 years it had the lowest values, and the increase in A.C.F. was significantly below that for the controls, 0·072 compared with 0·129, a difference of 0·057 (standard error = ± 0·022), but not significantly below that for the brown sugar group. The white sugar group also had a significantly smaller percentage than either of the other groups, of initially caries-free teeth which developed caries during the 2-year period of observation, the figures being 4·4 for the white sugar group, 8·1 for the brown sugar group and 8·8 for the controls.

In Table 8 are set out the findings for each type of deciduous tooth, upper and lower teeth being combined, for children who were aged 2 to 4 years inclusive at the beginning of the study. The only major differences between the results for the three groups occurred in regard to the children studied for 2 years; the white and brown sugar groups showed smaller increases in the A.C.F. and lower percentages of teeth developing caries during the period than the control group; these were significant for the second molars.

As the upper first are usually the most carious of all incisors, these have been separately analysed as a matter of interest, and the results are shown in Table 9. Figures are also given in this table for upper and lower, first and second molars combined, as these are the deciduous teeth upon which the Liverpool and Sheffield results are based, although, as explained previously (p. 7), a true comparison cannot be made between the absolute values in the London findings and those of the other two centres.

TABLE 9

London study: incidence, extent and spread of caries in upper first incisors and all molars in children aged 2 to 4 years

Types of deciduous teeth	Number of teeth			Percentage of teeth carious						Average caries figure						Increase in average caries figure			Percentage of non-carious teeth which developed caries during period		
				Beginning of period			End of period			Beginning of period			End of period								
	C*	W	B	C	W	B	C	W	B	C	W	B	C	W	B	C	W	B	C	W	B
Studied for 1 year																					
Upper first incisors ..	249	299	222	4·4	3·7	5·9	10·4	7·0	13·1	0·052	0·047	0·086	0·129	0·107	0·180	0·077	0·060	0·094	6·3	3·5	7·7
All molars	967	1,142	882	2·2	4·1	1·9	9·9	13·1	9·4	0·029	0·063	0·025	0·135	0·190	0·132	0·106	0·127	0·107	7·9	9·4	7·6
Studied for 1½ years																					
Upper first incisors ..	136	180	126	2·2	2·2	7·1	8·8	7·8	15·9	0·022	0·022	0·111	0·140	0·083	0·238	0·118	0·061	0·127	6·8	5·7	9·4
All molars	530	678	505	1·7	3·1	1·8	11·9	13·0	12·7	0·026	0·043	0·022	0·194	0·183	0·204	0·168	0·140	0·182	10·4	10·0	11·1
Studied for 2 years																					
Upper first incisors ..	59	64	39	0·0	6·3	5·1	10·2	12·5	23·1	0·0	0·063	0·051	0·119	0·172	0·333	0·119	0·109	0·282	10·2	6·7	18·9
All molars	236	231	160	0·4	4·8	1·9	19·5	14·3	16·3	0·008	0·069	0·019	0·301	0·229	0·225	0·293	0·160†	0·206	19·1	10·0†	14·6

* C = control group; W = white sugar group; B = brown sugar group.

† This value for the white sugar group is significantly smaller than that for the controls but not than that for the brown sugar group.

For the upper first incisors the order of the three groups was the same for each period of observation, the white sugar group having the least and the brown sugar group the greatest increase in incidence and spread of caries. In no case, however, was the difference between the groups significant.

The molars, on the other hand, showed no such consistent order, although the white sugar groups observed for $1\frac{1}{2}$ years and 2 years had less increase in caries than the other two groups. The only significant differences were between the control and white sugar groups for the 2-year period of observation. For the increase in A.C.F. the values were: white sugar 0·160 and controls 0·293, a difference of 0·133 (standard error $= \pm$ 0·053); the percentages of non-carious teeth developing caries during the period were: white sugar 10·0, controls 19·1, and the difference 9·1 (standard error $= \pm 3{\cdot}3$).

FACTORS POSSIBLY INFLUENCING INITIATION AND SPREAD OF CARIES

Although the object of the investigation was to test the effect of sugar on the initiation and spread of caries, other factors known to influence the carious process were considered to see whether they varied in the three groups of children and thus afforded one group an advantage over the others in any respect.

Structure of Teeth

Since teeth of good structure, as examined superficially or in section, had been shown (Mellanby, 1923, 1934) to be less susceptible to attack by caries than poorly formed teeth—i.e. teeth with defects which J. D. King (1940) referred to as M-hypoplasia, to distinguish them from the previously recognized gross hypoplasias—an attempt was made to assess the structure of the teeth of the children taking part in the London study. This was achieved in the majority of cases, but in some instances it had to be omitted, mainly owing to the difficulty of getting the children, especially the very young ones, to sit still for a long enough period. Structure was on the whole good, as gauged by the surface texture when the teeth were lightly rubbed with a right-angled probe (S.S. White, No. 37); the average hypoplasia figure (A.H.F.), which is calculated in a similar way to the A.C.F., was approximately 0·9 for all the teeth examined in this way. In each of the three groups of children there were very few teeth with severe M-hypoplasia (grade M-Hy_3) or gross hypoplasia, and only about 20 per cent with moderately severe defects of structure (grade M-Hy_2); the remainder were either normal or nearly so. Since these children, taken at random, were presumably representative of all in their respective groups, no group could be said to have any advantage over the others in the matter of susceptibility to caries on the grounds of dental structure.

Length of Residence in Homes

Another factor which might have been expected to have an effect upon the incidence of caries in these children was the length of time they had been in the homes. Since it is generally agreed that children in institutions have, in general, less caries than other children, the period of residence could be important if it showed considerable variation between the different groups; for instance if it varied by a matter of years. In the present study the authorities responsible for the children very kindly supplied such information as they had in their records, and the children's average length of residence in their present homes or any other similar institutions prior to the investigation, was estimated. The

largest difference between any two groups was only a matter of months, and any effect of institutional life could not be expected to influence the results of this study in so short a period.

Age Distribution

Again, the age distribution of the various groups of children and their average ages at the beginning of the study could have had some bearing on the caries incidence if the differences between them in these respects had been great. Unfortunately, it was not possible to equalize these factors since it was not known at the outset how many of the children then available would leave the homes within the space of a few weeks or months and how many would stay for the whole period of the investigation. The average ages of the three groups differed slightly for each of the three periods of study; in each case it was found that the control group had a slightly lower average, by a month or two, than either of the others, but there was probably not sufficient difference to influence the results of the study.

Diet

A variation in some important factor in the basal diet of the three groups might also have had some bearing on their increase in caries; but, as stated on p. 3, the fact that the investigation was made at a time when there was compulsory rationing of many staple foods ensured similarity of diet in the homes. Since the average diet of the groups differed only in a minor degree (see p. 13) this is unlikely to have affected the issue.

CONCLUSIONS (LONDON STUDY)

Comparisons have been made between groups of children having different levels of sugar intake, two groups eating approximately the same amount as that estimated to have been consumed by children of similar ages before the 1939–45 War (see Table 1, p. 4), and a third group, the controls, receiving about half that amount. The study provides no evidence that the higher level of sugar as administered in the diets of the London homes, promoted either the initiation or the spread of caries in deciduous teeth. This applies to both white (refined) and brown (unrefined or semi-refined) sugar. In the case of the children observed for 1 year only, the findings were similar in each of the three groups, and there were no significant differences between the groups observed for 18 months. Among the children, unfortunately few in number, who remained in the investigation for 2 years, those having additional white sugar had less increase in caries than either the controls or the brown sugar group. For the combined ages, 2 to 4 years, the increase in the A.C.F. of the white sugar group was significantly below that of the control group, and the percentage of non-carious teeth which developed caries during the period was significantly smaller than that of either the controls or the group having brown sugar.

B. Liverpool

HOME AND CHILDREN

In planning this part of the investigation and before deciding where it should be carried out and on which section of the child population, it was considered

desirable that certain conditions should be fulfilled in order that as many variables as possible could be eliminated. These conditions were as follows:

(a) The study should be carried out in a large home, provided that one with a sufficiently large number of children was available.

(b) The children should be resident the whole year round.

(c) All meals should be taken in the home.

(d) There should be a minimum wastage risk during a 2-year period.

(e) There should be equal sex and age distribution.

(f) There should be central cooking.

(g) Separate eating accommodation for sugar and control children should be available.

(h) There should be reliable supervision of sugar administration and full co-operation of the staff.

As it was decided, in view of the many variable factors which existed, to use one large home only, if possible, establishments with less than 150 available children were not considered suitable.

Nine homes in Lancashire and Cheshire were visited, two of which fulfilled the majority of the requirements listed. The children at one of them, however, had taken part a few years previously in an investigation into the effect on dental caries of topically applied potassium fluoride and the ingestion of sodium fluoride tablets (Stones, Lawton, Bransby and Hartley, 1949), and it was thought better not to include them in the present scheme.

It was therefore decided to carry out the study at the other institution, which is a Roman Catholic home and school run by the Liverpool Catholic Children's Protection Society for children deprived of parents and a normal home life. The children live collectively rather than by families, and eat, sleep and work according to their age-groups. When the investigation began there were nearly 300 suitable children at the home and these were divided equally into sugar and control groups. During the period which the investigation covered there was a steady drop in the numbers, due to the children leaving on account of their age or to return to their families.

Grouping of Children

Prior to the investigation, in March 1949, a clinical examination of the children between the ages of 3 and 14 years was carried out. The clinical records were sub-divided by sex and age-group, and for each age-group they were, as far as possible, placed in order of the total amount of caries. Children with a similar caries incidence were assigned by lot to one or other of the two groups. Thus, comparable pairs of 'sugar' and 'control' children were formed. Compromises had to be made to pair any 'odd' children left in certain age-groups, and children in neighbouring age-groups sometimes had to be paired.

The numbers of children observed over periods of 1, 1½ and 2 years in the two groups were as follows:

Group	1 *year*	1½ *years*	2 *years*
Control	112	91	83
Sugar	113	90	78
Totals	225	181	161

General Notes on the Home

The catering, including the planning of menus and the ordering and preparation of food, was carried out by the catering sister.

Because of administrative difficulties, it was not possible to have the sugar and control groups in separate rooms, but by seating all the 'sugar' children together at one side of the room and at their own tables, it was possible to have them separated from the other children. In each dining-room and at all meals there was a sister in charge to supervise the children, with at least one assistant. Extra food in the form of fruit, biscuits (cookies), sweets and cakes and the children's own sweet ration might be eaten at any time before the children went to bed.

At night and in the morning the children were made to clean their teeth; between breakfast and bedtime there was no oral hygiene as the children were not allowed near the dormitories.

DIETS DURING INVESTIGATION

Basal Diet

The diets of the two groups of children studied in Liverpool were very similar to those of the London children, except that more calories were consumed by the older Liverpool children. They all received their full rations of meat, fats, cheese and eggs and about 1½ pints of milk a day. Cod-liver oil and orange juice were given to the children under 6 years, and vegetables and fruit to all the children about as often as in the London homes (see Table 10). All the children had a simple evening meal at 6.30 p.m. For those under 6 years old the meal consisted of either plain bread and butter or sandwiches, accompanied by hot milk, while the rest of the children had either hot potatoes, egg, cheese or cold meat, with bread and butter and cocoa.

Sugar

Each child in the sugar group was given an additional 22 oz. of refined white sugar per week. Pre-war amounts of sugar were exceeded in some cases.

Administration of additional sugar. The dietitian checked the number of children in the five dining-rooms each month and gave a list to the catering sister who had full charge and weighed out the daily amount of additional sugar into coloured tins appropriate to the dining-rooms (3 oz. per child per week day, 4 oz. on Sundays). Each dining-room had two 7 lb. tins for the sugar, and each morning one would be taken to the catering sister to be filled.

The sister in charge of each dining-room supervised the detailed issue. Special tablespoon measures were provided, and it was found that the 3 oz. daily worked out to roughly one tablespoon of the granulated sugar per meal; on cereal at breakfast, on pudding at dinner, on fruit etc. at supper. Any balance was added to the cocoa drink in the evening. When puddings already had jam or syrup on them, the sugar was not taken by the children, but was kept in the tins and used more generously another time. By the end of the week each child in the sugar group, apart from eight older girls, had consumed 22 oz. of extra sugar.

The children had an annual holiday of five weeks, with a week's holiday at Whitsuntide, Easter and Christmas. The five weeks in the summer had been spent at Colwyn Bay, North Wales, for the last three years. During the holidays

the catering sister continued to supervise the children's feeding arrangements so that the extra sugar was given to the children in the same way as at the home and no difficulties were encountered.

Among the boys the additional sugar was received with enthusiasm from the beginning. Eight of the older girls (aged 14 years) had a definite dislike for the addition, and at first would tolerate only 2 oz. instead of 3 oz. per day. During the second year only two out of the eight persisted in their dislike. There were no refusals.

If a child was away in hospital or off sugar for health reasons for more than two weeks, he or she was crossed off the sugar group. When children were admitted to the school sick-bay with heavy colds or minor ailments the extra sugar was given them in granulated form, but when they had influenza or infectious illnesses they were given glucose instead, in hot drinks and on their cereals, pudding and fruit.

Dietary Checks

In order to estimate the amounts of food actually eaten by the children, dietary surveys lasting a week were carried out two or three times a year on

TABLE 10

Liverpool study: approximate average consumption per head of the main foods excluding sugar

Milk, fresh	10½ pints a week
Eggs	2–4 a week
Cheese, Fats, Meat and bacon ..	Full rations
Unrationed meat and offal (liver, kidneys etc.) ..	Once or twice a week
Fish	Once a week
Bread	Ad lib.
Cereals and porridge ..	Three times a week
Potatoes	Ad lib. every day
Green and root vegetables	Every day
Fresh fruit	Once or twice a week
Cod-liver oil, Orange juice	Daily to those under 6 years of age

small samples of the two groups. Estimates were made, without weighing, of the amounts eaten and drunk by six children in each group, two aged 5 years, two aged 9 and two aged 12, at every meal for one week. Calculations of the intakes of nutrients made from these surveys suggested that all recognized requirements were met, with the possible exception of protein and vitamin D in some of the children. Animal protein was well represented in the diets, but the protein from all sources apparently provided only some 10 per cent of the total calories instead of the 14 or 15 per cent which is regarded as desirable in children's diets. Vitamin D was present in sufficient amounts only in the diets of children who took cod-liver oil, i.e. those under 6 years of age.

Tables 10 and 11 give a summary of the information available about the amount of food eaten by the Liverpool children. It will be noticed that the diet

of the younger children, who received cod-liver oil and orange juice supplements resembles very closely that of the London children in all respects other than sugar content.

TABLE 11

Liverpool study: approximate average weekly sugar consumption per child

Source of sugar	Control group		Extra sugar group	
	Amount consumed (oz.)	Estimated sugar content* (oz.)	Amount consumed (oz.)	Estimated sugar content* (oz.)
Sugar, as such	10	10	32	32
Jam, syrup and honey ..	2¼	1½	2¼	1½
Chocolate, sweets ..	4¼	3½	4¼	3½
Total	16½	15	38½	37

* Refer to text (p. 4) for method of arriving at these figures.

DENTAL CARIES RESULTS

The data from this centre have been analysed by age and by period of observation; the results for deciduous molars are shown in Table 12 and for permanent molars in Table 13. It should be borne in mind that the figures given in these tables for both dentitions refer only to molars present at the time of the first inspection. No allowance is made, as is done in the London study, for teeth extracted because of caries prior to the investigation.

Deciduous Molars

One-year Study

The numbers of children concerned were 53 in the control group and 63 in the sugar group. All the deciduous molars present at the beginning of the inquiry were caries-free in about half of the children in both groups of each age-division, and the percentages of these teeth which were carious were fairly similar in the two groups. Among the children initially aged 4 to 6 years the sugar group had the larger increase in A.C.F. during the year, while among those aged 7 to 10 years they had the smaller, the difference in each age-group being insignificant. New carious molars as a percentage of non-carious molars at the first inspection followed the same trend as the A.C.F.

One-and-a-half-year Study

The number of children in the inquiry for 1½ years was 44 in the control and 48 in the sugar group. The percentage of children with caries-free molars and the percentage of carious molars at the beginning of the period were almost the same as for the 1-year period of exposure and there were no significant differences between the sugar and control groups. Again, as for the 1-year period, the increase in the A.C.F. of the children aged 4 to 6 years was greater for the sugar group than for the control group, but among those aged 7 to 10 years the controls had slightly higher values. In neither age-group was the difference significant. The percentage of molars which were non-carious at the first

TABLE 12

Liverpool study: incidence, extent and spread of caries in children aged 4 to 10 years: deciduous molars

Age at beginning of study (years)	Number of children		Number of molars		Percentage of children with caries-free molars				Percentage of molars carious				Average caries figure				Increase in average caries figure		Percentage of non-carious molars which developed caries during period	
					Beginning of period		End of period		Beginning of period		End of period		Beginning of period		End of period					
	C*	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S
Studied for 1 year																				
4 – 6	25	30	195	238	44·0	50·0	40·0	40·0	11·8	15·5	16·9	23·1	0·179	0·256	0·313	0·429	0·134	0·173	5·8	9·0
7 –10	28	33	202	231	53·6	57·6	35·7	51·5	10·9	13·0	15·8	15·6	0·178	0·225	0·282	0·307	0·104	0·082	5·6	3·0
Studied for 1½ years																				
4 – 6	21	25	163	200	38·1	52·0	38·1	32·0	12·3	12·5	18·4	24·5	0·184	0·170	0·362	0·465	0·178	0·295	7·0	13·7
7 –10	23	23	163	163	52·2	56·5	30·4	47·8	11·7	13·5	18·4	18·4	0·196	0·202	0·374	0·337	0·178	0·135	7·6	5·7
Studied for 2 years																				
4 – 6	21	21	163	168	38·1	47·6	38·1	28·6	12·3	13·7	20·2	31·5	0·184	0·190	0·411	0·625	0·227	0·435‡	9·1	20·7‡
7 –10	22	16	155	117	50·0	62·5	31·8	56·3	12·3	10·3	25·2	14·5	0·206	0·162	0·477	0·256	0·271	0·094†	14·7	4·8†

* C = control group; S = sugar group.

† The value for the sugar group is significantly smaller (see p. 29) than that for the controls.

‡ The value for the sugar group is significantly larger (see p. 29) than that for the controls.

TABLE 13

Liverpool study: incidence, extent and spread of caries in children aged 4 to 14 years: permanent first molars

Age at beginning of study (years)	Number of children		Number of 1st molars		Percentage of children with caries-free 1st molars				Percentage of 1st molars carious				Average caries figure				Increase in average caries figure		Percentage of non-carious 1st molars which developed caries during period	
					Beginning of period		End of period		Beginning of period		End of period		Beginning of period		End of period					
	C*	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S
Studied for 1 year																				
4 – 6	3	7	6	26	66·7	42·9	33·3	14·3	16·7	46·2	50·0	69·2	0·167	0·462	0·833	1·077	0·666	0·615	40·0	42·9
7 –10	48	47	185	187	35·4	27·7	27·0	14·9	35·7	44·4	51·9	66·8	0·470	0·567	0·811	0·989	0·341	0·422	25·2	40·4†
11 –14	31	30	122	114	29·0	23·3	22·6	6·7	39·3	39·5	53·3	58·8	0·607	0·535	0·869	0·974	0·262	0·439†	23·0	31·9
Studied for 1½ years																				
4 – 6	2	6	5	24	50·0	33·3	0·0	16·7	20·0	50·0	80·0	75·0	0·200	0·500	1·200	1·167	1·000	0·667	75·0	50·0
7 –10	40	35	155	139	40·0	31·4	22·5	11·4	32·9	40·3	56·8	70·5	0·432	0·511	0·981	1·122	0·549	0·611	35·6	50·6†
11 –14	24	25	94	94	29·2	16·0	16·7	8·0	38·3	45·7	58·5	69·1	0·574	0·628	0·947	1·213	0·373	0·585†	32·8	43·1
Studied for 2 years																				
4 – 6	2	6	5	24	50·0	33·3	0·0	16·7	20·0	50·0	100·0	79·2	0·200	0·500	1·800	1·417	1·600	0·917	100·0	58·3
7 –10	39	32	151	127	41·0	31·3	17·9	12·5	32·5	39·4	66·2	73·2	0·430	0·488	1·245	1·260	0·815	0·772	50·0	55·8
11 –14	18	21	70	80	22·2	14·3	16·7	9·5	42·9	46·3	65·7	75·0	0·629	0·638	1·114	1·388	0·485	0·750†	40·0	53·5

* C = control group; S = sugar group.

† The value for the sugar group is significantly larger (see pp. 29 and 30) than that for the control group.

inspection and which developed caries during the 18 months, did not differ significantly between the sugar and control groups for either age-group.

Two-year Study

The number of children in the inquiry for 2 years was 43 in the control and 37 in the sugar group. The relative amounts of caries at the beginning of the inquiry were similar to those of the groups observed for the shorter periods. The increase in extent and incidence of caries during the 2 years followed the same inconsistent trend in the two age-groups as in the other periods. The sugar group initially aged 4 to 6 years had an increase in A.C.F. of 0·435, which was significantly larger than the control group's value of 0·227, the difference being 0·208 (standard error $= \pm 0{\cdot}088$); and the percentage of caries-free molars which became carious during the period was also significantly larger for the sugar group, 20·7 compared with 9·1, a difference of 11·6 (standard error $= \pm 4{\cdot}2$). Among the children aged 7 to 10 years at the beginning of the study the trend was reversed and the increase in the A.C.F. for the sugar group, 0·094, was significantly less than for the controls, 0·271, the difference being 0·177 (standard error $= \pm 0{\cdot}06$); the percentage of caries-free molars which became carious was also significantly less for the sugar group, 4·8 as against 14·7 for the controls, a difference of 9·9 (standard error $= \pm 4{\cdot}0$).

Permanent First Molars

In the following comparisons, information from the age-group 4 to 6 years, although given in Table 13, has been ignored, since the numbers are too small to justify any conclusions.

One-year Study

The numbers of children in the inquiry, apart from the few aged 4 to 6 years, were 79 in the control group and 77 in the sugar group. The percentage of children with caries-free first molars at the beginning of the inquiry was slightly but insignificantly larger in the controls than in the sugar group for children aged 7 to 10 and 11 to 14, but the proportion of carious molars was the same for both groups aged 11 to 14, though greater in the sugar group aged 7 to 10 than in the controls. In both these age-groups the increase in incidence and extent of caries during the year was greater in the sugar than in the control group. The increase in the A.C.F. was very slightly larger in the sugar group aged 7 to 10, but significantly larger in the older children, being 0·439 for the sugar and 0·262 for the control group, a difference of 0·177 (standard error $= \pm 0{\cdot}078$). A larger proportion of the molars which were caries-free at the first inspection became carious during the year in the sugar group than in the control, but only in those children aged 7 to 10 years at the beginning of the study was the difference significant, 15·2 (standard error $= \pm 6{\cdot}2$) when the values were 40·4 and 25·2.

One-and-a-half-year Study

Apart from the 4 to 6-year-olds, there were 64 children in the control and 60 in the sugar group who were under observation for $1\frac{1}{2}$ years. The control group had a larger proportion of children with caries-free first molars and a slightly smaller amount of caries at the beginning of the period than the sugar group, but the difference was not significant. The spread of the disease during the 18 months followed a similar trend to that for the 1-year period. The increase

in the A.C.F. was larger in the sugar group, not significantly so in the younger children, but in those who were initially 11 to 14 years the value for the sugar group, 0·585, was significantly larger than that for the controls, 0·373, the difference being 0·212 (standard error $= \pm 0{\cdot}097$). In both these age-groups the percentage of non-carious molars which became carious during the period was larger in the sugar than in the control group. The difference between the two groups was significant only with the younger children; the percentages for these groups were 50·6 for sugar and 35·6 for controls, a difference of 15·0 (standard error $= \pm 7{\cdot}3$).

Two-year Study

Excluding the youngest age-group, there were 57 children in the control and 53 in the sugar group who remained under observation for 2 years. As in the other periods of study the control group had more children with caries-free first molars and slightly less caries at the beginning of the period than the sugar group. During the 2 years the increase in the A.C.F. for children aged 7 to 10 years was a little smaller in the sugar group than in the control group. Among those aged 11 to 14, the sugar group, with a value of 0·750, had a significantly greater increase than the controls, whose value was 0·485, a difference of 0·265 (standard error $= \pm 0{\cdot}12$). The proportion of non-carious first molars which developed caries during the period was, in both age-groups, larger for the sugar than the control group, but the differences were not significant.

CONCLUSIONS (LIVERPOOL STUDY)

The sugar group initially aged 4 to 6 years showed a greater increase in caries of the deciduous molars than the control group in each period of observation, and a significantly greater increase in the 2-year period. Among the 7 to 10-year-old children the position was reversed and the controls had the greater increase in caries, which was statistically significant in the 2-year period of observation. The percentage of non-carious deciduous molars which had developed caries at the end of 2 years showed a similar contradictory trend; for the 4 to 6-year-old children it was significantly less, and for the 7 to 10-year-olds significantly greater in the controls than in the sugar group. The increase in the A.C.F. of the first permanent molars of the children initially aged 11 to 14 years was significantly larger for the sugar than for the control group in each of the three periods of observation. Among the children aged 7 to 10, however, the increase was only slightly larger for the sugar group than for the controls observed for 1 year and $1\frac{1}{2}$ years respectively and a little smaller for the sugar group under observation for 2 years. The percentage of non-carious molars which developed caries during the inquiry was in all cases greater in the sugar than in the control groups and significantly so in the 7 to 10-year-old children who were studied for 1 year and for $1\frac{1}{2}$ years.

The conflicting age-incidence of caries in this centre may be due to the small number of children on whom the results are based. The small number exposed to risk prevents any definite conclusions being drawn, but the general results seem to indicate that sugar, given under these conditions, is not the decisive factor in caries development.

C. Sheffield

The Sheffield section of the investigation was confined to the essentials of the scheme proposed by the Dental Research Committee; no additional investigations were attempted.

HOMES AND CHILDREN

The study was carried out at a group of cottage homes situated on the outskirts of Sheffield and housing over 300 children. The homes are under the general supervision of the Superintendent and Matron and are divided into a nursery and a number of cottages, each in the immediate charge of a foster-mother. The older children attend various schools in the city. Their routine medical and dental treatment is carried out by the Sheffield Education Authority under the School Health Service.

For the period of this study a part-time dietitian was employed to pay regular visits to the homes and to supervise the administration of the additional sugar.

It was not possible to include in the investigation either the nursery children or those in the reception cottages, who were only there temporarily; but some 200 children, ranging in age from 4 to 14 years, were available, and it was expected that 75 per cent of them would remain in the homes for the 1½ years' period of the sugar test.

Mouth hygiene varied, but as a rule the children cleaned their teeth once or twice a day.

Grouping of Children

As in Liverpool, the children to be studied were divided into two groups. The first, consisting of 86 children from seven of the cottages, acted as controls, and the other, in which there were 113 children from nine cottages, received additional sugar.

The numbers remaining in the scheme for 1 year and for 1½ years were as follows:

Group	1 *year*	1½ *years*
Control	57	36
Sugar	89	57
Totals	146	93

This unexpectedly large loss of children was, as in the other centres, the result of a more active policy of 'boarding out' than had previously been pursued.

Since the success of an investigation of this kind depends greatly on the co-operation of the staff—in this case, particularly the foster-mothers—the reasons for and objects of the scheme were explained to them in a preliminary talk. The result was that their willing help was enlisted and relations between the staff of the homes and the investigating team were of the most cordial nature.

DIETS DURING INVESTIGATION

Basal Diets

For five days in the week the midday meal was provided by the School Meals Service, so that during school terms only breakfast and tea were provided in the homes. No suppers were given to any of the children.

Non-perishable foods were issued weekly to each cottage. Other foods were requisitioned as required by the foster-mothers, each of whom prepared the menus for her own cottage. All the children received their full ration of meat fat, cheese and eggs. The amount of milk issued in the homes was 7 pints per child per week during the winter and spring, and 9 pints in the summer when there was no rationing; in addition the children of school age received $\frac{1}{3}$ pint per day at school. Cod-liver oil and orange juice were issued daily to the children in each cottage. The ordinary diet, inclusive of school meals, was investigated by the dietitian and found to be satisfactory according to modern standards. Although there was a considerable age-range in each cottage an adequate calorie and protein intake was available for all. The approximate average consumption per head of the main foods other than sugar is shown in Table 14.

TABLE 14

Sheffield study: approximate average consumption per head of the main foods

Milk, fresh	$9\frac{1}{3}$–$11\frac{2}{3}$ pints a week, according to season
Eggs Cheese Fats Meat and bacon ..	Full rations
Unrationed meat and offal (liver, kidneys etc.) ..	Once or twice a week
Fish	Every Friday in the home and once in three weeks at school
Bread	Ad lib.
Cereals or porridge ..	Usually once or twice a week
Potatoes	Ad lib. every day
Green and root vegetables	Most days, salads occasionally
Fresh fruit	Occasionally
Cod-liver oil Orange juice	Daily

Sugar

The quantity of sugar in the diet of the control group was about $19\frac{1}{2}$ oz. per week in winter and $23\frac{1}{2}$ oz. in summer, the extra amount being derived from the special issue for jam-making. These figures included not only sugar used as such but also the estimated amount contained in jam, marmalade, syrup, sweets and chocolates. The addition of 22 oz. of white, refined sugar to the diets of the other group raised the total weekly consumption of this group to $41\frac{1}{2}$ oz. per child in winter and $45\frac{1}{2}$ oz. in summer. Thus both the control and the sugar groups had rather more sugar than their counterparts in Liverpool. Details of the sugar intake are given in Table 15.

Administration of additional sugar. The sugar was weighed and distributed weekly from the general stores in 22 oz. portions to the cottages in which the sugar group lived. Each child had a labelled container holding the full amount and this was filled weekly by the foster-mother.

The children were allowed to use the sugar as they wished—in tea or cocoa, on bread and butter, on milk puddings, porridge, etc. They acquired the habi

TABLE 15

Sheffield study: approximate average weekly sugar consumption per child

Source of sugar	Control group		Sugar group	
	Amount consumed (oz.)	Estimated sugar content* (oz.)	Amount consumed (oz.)	Estimated sugar content* (oz.)
Full sugar ration taken by all	10	10	10	10
Extra ration eaten at school	2	2	2	2
Extra amount for test group	—	—	22	22
Jam, marmalade and syrup	6	4	6	4
Chocolate and sweets ..	4	3½	4	3½
Winter total	22	19½	44	41½
Extra sugar ration in summer for jam-making	4	4	4	4
Summer total	26	23½	48	45½

* Refer to text (p. 4) for method of arriving at these figures.

of using much of it in tea and cocoa. It is of interest that when having food outside the homes they thought the tea was served unsweetened. In the early months the boys took their extra sugar more readily than the girls. During the school terms much extra sugar had to be eaten at the two meals per day taken in the homes, whereas at the weekends and during holidays it could be spread over the three meals.

It was not found that as a result of taking the sugar there was any decrease in the desire for preserves. In summer the extra sugar issued for jam was used for making lemon curd and sweets.

The 'official' sweet ration (2 oz. per week) was usually distributed after the daily dose of cod-liver oil. It was estimated that the children received, on the average, another 2 oz. a week from visitors.

Towards the end of the 18 months the dietitian reported that the children were tired of the increased sugar, and the foster-mothers felt that in view of this intolerance they could not be persuaded to continue for much longer. It was therefore decided to terminate the study at the end of this period and not, as in London and Liverpool, to continue for a further 6 months. Some concern was, however, felt by the foster-mothers about the effect of the sudden stopping of the extra sugar at the end of the test period. It was therefore arranged for a gradually diminishing supply to be available after the final dental inspection.

DENTAL CARIES RESULTS

The children at this centre were divided into two age-groups, 4 to 6 and 7 to 10 years, for deciduous teeth, and another two, 7 to 10 and 11 to 14 years for permanent teeth. The results obtained for the deciduous molars are shown in Table 16 and those for the permanent first molars in Table 17. It should be noted that, as in the Liverpool study, the figures given here for both dentitions refer only to molars present at the time of the first inspection. No allowance is made,

TABLE 16

Sheffield study: incidence, extent and spread of caries in children aged 4 to 10 years: deciduous molars

Age at beginning of study (years)	Number of children		Number of molars		Percentage of children with caries-free molars				Percentage of molars carious				Average caries figure				Increase in average caries figure		Percentage of non-carious molars which developed caries during period	
					Beginning of period		End of period		Beginning of period		End of period		Beginning of period		End of period					
	C*	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S
	Studied for 1 year																			
4 – 6	13	20	102	160	38·5	85·0	38·5	75·0	19·6	7·5	20·6	10·0	0·275	0·119	0·392	0·181	0·117	0·062	1·2	2·7
7 – 10	17	22	128	165	41·2	50·0	23·5	40·9	19·5	20·0	28·1	23·6	0·273	0·467	0·523	0·545	0·250	0·078†	10·7	4·5
	Studied for 1½ years																			
4 – 6	10	10	78	80	30·0	80·0	10·0	60·0	24·4	8·8	29·5	16·3	0·346	0·125	0·564	0·300	0·218	0·175	5·4	8·1
7 – 10	14	17	104	128	35·7	58·8	14·3	35·3	19·2	18·0	36·5	21·9	0·269	0·438	0·673	0·523	0·404	0·085†	21·4	4·8†

* C = control group; S = sugar group.

† The value for the sugar group is significantly smaller (see p. 36) than that for the controls.

TABLE 17

Sheffield study: incidence, extent and spread of caries in children aged 7 to 14 years: permanent first molars

Age at beginning of study (years)	Number of children		Number of 1st molars		Percentage of children with caries-free 1st molars				Percentage of 1st molars carious				Average caries figure				Increase in average caries figure		Percentage of non-carious 1st molars which developed caries during period	
					Beginning of period		End of period		Beginning of period		End of period		Beginning of period		End of period					
	C*	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S
Studied for 1 year																				
7–10	23	31	92	120	60·9	51·6	43·5	38·7	27·2	25·8	32·6	37·5	0·272	0·300	0·348	0·492	0·076	0·192†	7·5	15·7
11–14	19	35	72	137	26·3	31·4	26·3	20·0	50·0	48·2	56·9	56·9	0·722	0·591	0·833	0·745	0·111	0·154	13·9	16·9
Studied for 1½ years																				
7–10	16	23	64	88	62·5	56·5	31·3	30·4	26·6	19·3	40·6	43·2	0·266	0·216	0·484	0·511	0·218	0·295	19·1	29·6
11–14	10	22	39	86	40·0	31·8	20·0	13·6	41·0	44·2	51·3	62·8	0·692	0·535	0·872	0·884	0·180	0·349	17·4	33·3

* C = control group; S = sugar group.

† The value for the sugar group is significantly larger (see p. 36) than that for the controls.

as is done in the London study, for teeth extracted because of caries prior to the investigation.

Deciduous Molars

One-year Study

There were 30 children in the control group and 42 in the sugar group. At the beginning of the inquiry a larger proportion of the 4 to 6-year-old children in the sugar group had caries-free molars than in the control group, 85·0 compared with 38·5 per cent, and the percentage of carious molars was smaller than in the control group, 7·5 compared with 19·6. Among the 7 to 10-year-olds there was only a small difference between the two groups in their initial caries level. During the year the sugar group in both age-divisions showed a smaller increase in the A.C.F. than the controls; the difference between those initially aged 4 to 6 years was not significant, but among the 7 to 10-year-olds the increase in the sugar group, 0·078, was significantly below that in the control group, 0·250, the difference being 0·172 (standard error = ± 0·06). Practically no difference occurred between the younger groups in the percentage of non-carious molars which became carious during the inquiry, but in the older groups the children eating extra sugar had the smaller percentage, though the difference was not significant.

One-and-a-half-year Study

The number of children observed for 1½ years was 24 in the control and 27 in the sugar group. The percentage of children with caries-free molars and the percentage of carious molars at the beginning of the investigation followed a similar pattern to that for the children studied for 1 year. The sugar group again showed a smaller increase in the A.C.F. than the controls, and for the 7 to 10-year-olds it was significantly smaller, 0·085 compared with 0·404, the difference being 0·319 (standard error = ± 0·08). The percentage of non-carious molars which became carious during the period was slightly larger for the sugar group aged 4 to 6 years initially than for the controls, but among the children aged 7 to 10, the sugar group, with 4·8 per cent, had significantly less than the controls, with 21·4 per cent, the difference being 16·5 (standard error = ± 5·0).

Permanent First Molars

One-year Study

There were 42 control children and 66 in the sugar group. In each age-division both groups had similar amounts of caries at the beginning of the inquiry when judged by the percentage of children with caries-free permanent first molars and the percentage of these teeth that were carious. The children having additional sugar showed larger increases in the A.C.F. than the controls, but only among those aged 7 to 10 years initially was the difference significant, 0·116 (standard error = ± 0·50), when the increase in the A.C.F. was 0·192 for the sugar group and 0·076 for the controls. Both sugar groups also showed slightly larger values than the controls for the percentage of non-carious teeth which became carious during the inquiry.

One-and-a-half-year Study

The number of children observed for 1½ years was 26 in the control and 41 in the sugar group. The proportions of children with caries-free first molars

and of these teeth with caries, were not, at the beginning of the investigation, appreciably different in the sugar and control groups of either age-division. Both groups having additional sugar had larger increases in the A.C.F. and larger percentages of teeth becoming carious during the period than the controls, but the differences were not significant.

CONCLUSIONS (SHEFFIELD STUDY)

The numbers of children in the various sub-groups were too small for any firm conclusions to be drawn from them. The effect of sugar, if any, appears, as in the Liverpool study, to have differed with the type of dentition. For the deciduous molars the sugar group had a smaller increase in the A.C.F. than the controls, the difference being significant in the 7 to 10-year-old children for both periods of observation. The percentage of non-carious molars developing caries during the inquiry was approximately the same for both the sugar and control groups aged 4 to 6 years initially, but the sugar group aged 7 to 10 had less new caries than their controls, the difference being significant for the $1\frac{1}{2}$ years' period of observation. For the permanent first molars, on the other hand, the increase in the A.C.F. and the percentages of teeth developing caries during the investigation were larger for the sugar group than for the controls in each age-group during both periods of observation, but the only significant difference was that found in the A.C.F. increase of the 7 to 10-year-old children studied for 1 year.

D. Liverpool and Sheffield Combined

DENTAL CARIES RESULTS

In order to obtain larger numbers of observations in each group and thereby decrease the chance fluctuations in trends, the results from the Liverpool and Sheffield inquiries have been combined, for ages 4 to 6 and 7 to 10 years for the deciduous molars, and for 7 to 10 and 11 to 14 years as regards the permanent first molars, for the 1-year and $1\frac{1}{2}$-year periods of observation. These age-groups and periods are common to both centres. The results for the deciduous molars are shown in Table 18 and for the permanent first molars in Table 19. The figures given here for both dentitions refer only to molars present at the first inspection. No allowance is made, as is done in the London study, for teeth extracted because of caries prior to the investigation.

Deciduous Molars

One-year Study

The total numbers of children concerned in the two centres were 83 controls and 105 in the sugar group. The proportion of children with caries-free molars at the beginning of the inquiry was larger in the sugar than in the control group for both age-divisions, 4 to 6 and 7 to 10 years, but the percentages of carious molars in the two groups were very similar for each age-division. The increase in the A.C.F. during the period was the same for both of the younger groups, but slightly smaller for the sugar group aged 7 to 10 initially. The percentage of non-carious molars which developed caries during the period was slightly higher in the 4 to 6-year-old children and slightly lower in those of 7 to 10 years for the sugar group than for the controls, but neither of the differences was significant.

TABLE 18

Liverpool and Sheffield studies combined: incidence, extent and spread of caries in children aged 4 to 10 years: deciduous molars

Age at beginning of study (years)	Number of children		Number of molars		Percentage of children with caries-free molars				Percentage of molars carious				Average caries figure				Increase in average caries figure		Percentage of non-carious molars which developed caries during period	
					Beginning of period		End of period		Beginning of period		End of period		Beginning of period		End of period					
	C*	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S
													Studied for 1 year							
4 – 6	38	50	297	398	42·1	64·0	39·5	54·0	14·5	12·3	18·2	17·8	0·212	0·201	0·340	0·329	0·128	0·128	4·3	6·3
7 –10	45	55	330	396	48·9	54·5	31·1	47·3	14·2	15·9	20·6	18·9	0·215	0·326	0·375	0·407	0·160	0·081	7·4	3·6
													Studied for 1½ years							
4 – 6	31	35	241	280	35·5	60·0	29·0	40·0	16·2	11·4	22·0	22·1	0·237	0·157	0·427	0·418	0·190	0·261	6·9	12·1
7 –10	37	40	267	291	45·9	57·5	24·3	42·5	14·6	15·5	25·5	19·9	0·225	0·306	0·491	0·419	0·266	0·113†	12·7	5·3†

* C = control group; S = sugar group.

† The value for the sugar group is significantly smaller (see p. 40) than that for the controls.

TABLE 19

Liverpool and Sheffield studies combined: incidence, extent and spread of caries in children aged 7 to 14 years: permanent first molars

Age at beginning of study (years)	Number of children		Number of 1st molars		Percentage of children with caries-free 1st molars				Percentage of 1st molars carious				Average caries figure				Increase in average caries figure		Percentage of non-carious 1st molars which developed caries during period	
					Beginning of period		End of period		Beginning of period		End of period		Beginning of period		End of period					
	C*	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S
Studied for 1 year																				
7–10	71	78	277	307	43·7	37·2	32·4	24·4	32·9	37·1	45·5	55·4	0·404	0·463	0·657	0·795	0·253	0·332	18·8	29·0†
11–14	50	65	194	251	28·0	27·7	24·0	13·8	43·3	44·2	54·6	57·8	0·649	0·566	0·856	0·849	0·207	0·283	20·0	24·3
Studied for 1½ years																				
7–10	56	58	219	227	46·4	41·4	25·0	19·0	31·0	32·2	52·1	59·9	0·384	0·396	0·836	0·885	0·452	0·489	30·5	40·9
11–14	34	47	133	180	32·4	23·4	17·6	10·6	39·1	45·0	56·4	66·1	0·609	0·583	0·925	1·055	0·316	0·472†	28·4	38·4

* C = control group; S = sugar group.

† The value for the sugar group is significantly larger (see p. 40) than that for the controls.

One-and-a-half-year Study

The numbers of children who remained in the investigation for 1½ years were 68 in the control group and 75 in the sugar group. The relative positions of the sugar and control groups in the amount of caries at the beginning of the inquiry were similar to those of the children observed for 1 year. During the 1½ years the A.C.F. increased a little more in the sugar group aged 4 to 6 years than in the corresponding controls, but the difference between the two groups was not significant. Among the older children the sugar group had a significantly smaller increase in the A.C.F. than the controls, 0·113 compared with 0·266, a difference of 0·153 (standard error = ± 0·045). The percentage of caries-free molars which developed caries during the period followed the same pattern as the A.C.F., and the value for the sugar group aged 7 to 10 initially, namely 5·3, was significantly smaller than that for the control group, 12·7, a difference of 7·4 (standard error = ± 2·6).

Permanent First Molars

One-year Study

The total numbers involved in the two centres for the study of the permanent teeth were 121 children in the control and 143 in the sugar group. At the beginning of the period the sugar group aged 7 to 10 years had a slightly larger amount of caries than the corresponding control group, but the two older groups aged 11 to 14 had approximately equal amounts. The increase in the A.C.F. was a little larger in both age-groups for the sugar than for the control group, but the difference in each case was not significant. The sugar group had also a larger percentage of permanent first molars which developed caries during the period than the control group, but only among the 7 to 10-year-old children was the difference significant, when the values were 29·0 and 18·8, a difference of 10·2 (standard error = ± 4·4).

One-and-a-half-year Study

Ninety of the control children and 105 of the sugar group were under observation for 1½ years. The amount of caries at the beginning of the period was slightly larger in the sugar group than in the control for children of both age-divisions, as was the case in the 1-year period of observation. The increase in the A.C.F. during the period was also very slightly larger in the sugar group aged 7 to 10 years initially, but significantly larger in the 11 to 14-year-old group, the value for the latter being 0·472 as compared with 0·316 for the control group, a difference of 0·156 (standard error = ± 0·068). Ten per cent more of the non-carious teeth developed caries during the 1½ years in the sugar group than in the control group in both age-divisions, but this difference was not quite significant.

CONCLUSIONS
(LIVERPOOL AND SHEFFIELD STUDIES COMBINED)

The increases in the incidence and extent of caries in the deciduous molars were quite low for the 1-year period of observation and there were only small insignificant differences between the two groups of children. In the 18 months' period the deciduous molars of the 4 to 6-year-olds in the sugar group developed

more, but not significantly more, new caries and had a slightly greater increase in the A.C.F. than the control group, while among the 7 to 10-year-old children the sugar group had significantly less increase than the controls. The spread of caries in the permanent first molars of the children having additional sugar was greater than that of the controls for both age-groups and for both periods of observation, but the difference was only significant for the A.C.F. of the 11 to 14-year-olds studied for 18 months and for the percentage of non-carious molars developing caries during the period for the 7 to 10-year-old children under observation for 1 year.

Taken together, the deciduous molars and permanent first molars of the children in the combined Liverpool and Sheffield studies do not appear to show any evidence that additional sugar given in the diets had any harmful effect during the periods under review.

V. Discussion and Conclusions

For many years there has been a widespread impression amongst dentists and the laity that dental caries is intimately associated with the amount and form of the sugar intake, but scientific proof of the validity of this impression has been lacking. Obviously, if it were correct, attempts to prevent caries should be in the direction of diminishing the sugar intake or sugar fermentation in the mouth, but until we know whether the amount of the sugar intake is in fact responsible we are groping in the dark. One logical step, therefore, was to carry out a sufficiently wide investigation for a clear answer to be obtained, and with this end in view three simultaneous studies were made by the authors, in the London area, in Liverpool and in Sheffield, to test the effect on the initiation and spread of caries of different amounts of sugar, taken as ordinarily consumed in the diet.

The following are the salient points concerning the plan of the investigation:

1. The studies were limited to children and included both deciduous and permanent teeth, although deciduous teeth predominated.

2. The children ranged in age from 2 to 14 years at the beginning of the investigation; those in the London study were all infants of 2 to 4 years old, while those in Liverpool and Sheffield were from 4 years of age upwards.

3. All the children were living in residential homes (institutions) and were receiving basal diets of good nutritional quality.

4. In each study there were control and test groups, the latter receiving additional sugar as part of the diet. In London both white (refined) and brown (unrefined and semi-refined) sugars were tested, whereas in Liverpool and Sheffield only the white variety was used. It was found that many of the London children could not tolerate over a long period a total intake from all sources of more than approximately 22 oz. of sugar per week, a figure which was, even so, slightly higher than the estimated pre-war consumption for this young age-group. It was therefore arranged that the control group should have 11 oz., which was rather less than their war-time and early post-war amount, and that the high sugar groups should have the 22 oz., which they could manage without difficulty. In Liverpool and Sheffield, where the children were older, the test was so planned that the control groups should have the total amount then current in the homes, while the test groups had an additional 22 oz., bringing their total—37 oz. in Liverpool and 41½ to 45½ oz. in Sheffield—up to or above the estimated approximate pre-war level.

5. In the London study all deciduous teeth present at the first inspection, together with the few molars which had previously been extracted because of caries, were included in the caries estimations; there were no permanent teeth present initially in the mouths of these young children. In the other two studies the condition of all teeth present was recorded but, because of complications arising from continuous shedding and eruption, only the deciduous first and second molars of the children aged 4 to 10 years, and the permanent first molars of those aged 7 to 14 years, were used for analysis. All such molars missing at the first inspection in these two studies were ignored.

6. It was intended that the investigation should continue for a minimum of 1 year and a maximum of 2 years.

The results of the investigation are, in the main, clear cut and therefore can be stated quite briefly. They demonstrate that relatively great differences in the total sugar content of the diets of children in institutions had no significant effect on the initiation or spread of dental caries in periods of 1 to 2 years.

As regards the *deciduous* teeth, there is, as a whole, no evidence that additional sugar, white or brown, as administered in this investigation, resulted in any increase in caries. Although there were some discrepancies between the various findings, these were inconsistent among themselves and usually small, and can therefore be regarded as cancelling out. In general, there was actually in each centre an apparent tendency for a reduction in caries of the deciduous teeth in the groups taking additional sugar. For instance, in the London area the control group aged 2 to 4 years had a larger increased incidence and spread of caries during the test periods than the other children, and significantly larger than the white sugar group. Again, in the Liverpool and Sheffield groups combined, the molars of the controls aged 7 to 10 years showed a significantly greater increased incidence and spread of caries than those of the corresponding sugar group for the $1\frac{1}{2}$ and 2 years' periods of observation. On the other hand, in the Liverpool children aged initially 4 to 6 years, the sugar group after 2 years showed a significantly greater increase in caries than the control group.

As far as the *permanent* first molars were concerned, while the sugar groups tended to show a slightly greater increase in and spread of caries than the control groups, on balance the total figures available for these teeth did not disclose any consistently significant differences. For instance, in the Liverpool and in the combined Liverpool and Sheffield studies the percentages of new carious molars in the 7 to 10-year-old children observed for only 1 year were significantly larger in the sugar groups than in the controls, but the spread of caries, expressed as the increase in the A.C.F. (average caries figure: see p. 7), was not significant. When Sheffield was considered by itself, the opposite result was obtained. Again, in the combined groups of children aged 11 to 14 years who were observed for $1\frac{1}{2}$ years, and in the Liverpool group observed for 2 years, the increase in the A.C.F. of the sugar groups was significantly greater than that of the controls, whereas the percentages of new carious molars were not significantly higher.

Thus, the results of the three separate studies, which were geographically quite distinct and were conducted by different observers who knew nothing of each other's results until the end, are all essentially similar. It seems probable that the apparent anomalies in the findings for both deciduous and permanent teeth are chance variations due to small numbers when the main groups of

children are split into sub-groups, since they show no consistency when the results are surveyed as a whole; it also seems unlikely that sugar affects the two dentitions differently.

It is worthy of note that the findings for the London group having brown (unrefined or semi-refined) sugar do not uphold the view of Osborn *et al.* (1937) that unrefined sugar contains some factor, lacking in the purified product, which tends to protect the teeth from caries. The underlying idea in making the test was that, if the sugar groups did in fact show a significant increase in caries, then if the unrefined sugar had a protective effect, the group having some of this product would not share to the same extent in the increase. If that had proved to be so then a very important practical point, highly relevant to the significance of the sugar intake in caries, would have been established. As it turned out, since high dietary sugar *per se* had no caries-promoting effect, the brown sugar group lost some of its importance. However, it was of value in providing an additional sugar group which showed a caries experience similar to that of the white sugar group and of the controls.

In this Report we have been concerned with the results of a particular investigation and not with the problem of the study of dental caries in general. Nevertheless, the results provide a basis for a very broad appraisal of the present situation. Few of those concerned with the problem now doubt that it is primarily, in the broadest sense, dietetic in nature. The undoubted effect of 'civilized' diets on populations previously receiving 'natural' diets is a strong pointer to this idea. The real problem is, what aspect of the diet is at fault? Is it a local and external or systemic and internal effect on the tooth, or both? The local effect is generally held to be due to bacterial fermentation products of carbohydrate or to altered bacterial flora as the result of high sugar concentration on the tooth surface. The hypothetical local effect may, according to some, be of a purely physical nature due either to lack of adequate cleansing by fibrous foods, which favours an accumulation of bacterial substrates on the tooth surface, or to malocclusion and other irregularities, caused by inadequate use of the muscles of mastication due to soft foods. The other view is that as a result of certain kinds of faulty nutrition, especially as regards the calcifying properties of the diet during the period of development, the tooth structure is defective and so is more susceptible than that of well-formed teeth to caries, and also that, post-eruptively, similar faulty diets lower the resistance of the formed teeth, whatever their structure. These two hypotheses are, of course, not mutually exclusive; indeed, by analogy with many pathological states, one would expect them to operate together.

In the present investigation, another step has been made towards eliminating one by one the various hypotheses, so that ultimately the more probable ones may be pursued. It has been seen that neither a high sugar nor a low sugar intake affected the teeth of children receiving diets which were adequate according to modern standards and contained liberal supplies of milk and cod-liver oil. It is clear, therefore, that the high refined-sugar content of our 'civilized' diets, provided they are otherwise nutritionally good in the sense mentioned above, is not necessarily harmful to the teeth. The investigation does not, of course, throw any direct light on whether a more prolonged high local concentration of sugar on the tooth surface influences the carious process; nor does it show whether a high sugar diet in itself, if taken during the whole period of tooth formation, would affect the composition of the teeth. There is, however,

evidence from this and other investigations that carious teeth continue to appear in children receiving these so-called adequate diets, even with a low sugar intake. If, as there is reason to think, correct nutrition is important in tooth structure and in the resistance of erupted teeth to caries, then, in addition to the known factors mentioned above, there must be others, still to be identified, which can be, and often are, deficient in our modern diet.

In conclusion, it may be said that, while this investigation does not prove that the sugar content of the diet, *however distributed and however eaten*, never affects the teeth, it certainly points to the practical conclusion that, provided a child is fed on a diet as good as that of the average children's residential institution in England, a substantial increase in the amount of sugar in the diet will not affect the child's liability to dental caries within a period of at least 2 years.

APPENDIX I

Other Investigations in the Liverpool Study

A. EFFECT OF INCREASED SUGAR INTAKE ON ACIDOGENIC FLORA OF SALIVA

Jay (1947) found that there was a relationship between a high carbohydrate intake and the number of lactobacilli in the mouth. He reported that by reducing the daily intake of carbohydrate to approximately 100 g. for a period of two weeks the lactobacillus counts were reduced.

It was desired, therefore, in this investigation to study the effect of an increased sugar intake by comparing the lactobacillus counts of children in the sugar and control groups, to determine whether the children in the sugar group would show much higher counts than those in the control group.

Similarly, it was decided to ascertain whether the rate of total acid production of whole saliva would be increased in the children in the sugar group compared with the control group.

Tests

Two tests were used to check these possibilities:

(a) *Lactobacillus count* (Hadley, 1933). This test gives an estimate of the number of aciduric organisms per ml. of saliva. The resultant counts were scored as follows:

Lactobacillus count	*Score*
Over 300,000	4
300,000–50,000	3
50,000–1,000	2
1,000–100	1
100–0	0

(b) *Snyder's colorimetric test* (Snyder, 1940). This test measures the rate of acid production of whole saliva. The readings were scored as follows:

Colour change from green to yellow:	*Score*
<24 hours	4
24–48 „	3
48–72 „	2
72–96 „	1
>96 „ (or no change)	0

Selection of Children

One hundred and nine children were selected, 55 in the sugar group and 54 in the control group. These children had been paired on the basis of age, sex and caries activity following a clinical examination before the investigation began. Their age-range was from 6 to 14 years.

Collection of Saliva Specimens

Collections were made at the beginning, during, and at the end of the major investigation as follows: June 1949, September 1950 and June 1951. Three specimens, one on each of three different days, were obtained during this period.

Administrative difficulties prevented a supervised early-morning collection. Specimens were obtained shortly after midday on each occasion. The specimens provided saliva for both the lactobacillus count and the Snyder test.

Method of Collection

Saliva flow was stimulated with paraffin wax lozenges made from a low-melting-point wax. One ounce universal glass bottles with rubber-lined screw caps were used for the saliva, and the collection was completed in 5 to 10 minutes. As the investigation progressed the children became expert at producing large volumes of saliva in under 5 minutes. Between 5 and 10 ml. was the amount required. The children were instructed to scour the tooth surfaces with the wax, and to keep the lid on the bottle when not spitting, to avoid outside contamination.

Numbers of Children at each Examination

During the 2-year period, the numbers, which declined at each successive examination due to the departure of children from the home, were as follows:

	Sugar group	*Control group*
June 1949	55	54
September 1950 ..	45	39
June 1951	35	32

Comments

The procedures employed for the estimation of the number of lactobacilli per 1 ml. of saliva can be criticized. Many sources of potential error exist. Amongst the more important ones are variations in:

(a) The content and physical character of the diet during the 24 hours prior to collection.

(b) The thoroughness with which the children brush their teeth.

(c) The co-operation of the children in chewing the paraffin wax lozenges so that all tooth surfaces are scoured.

(d) The rate of saliva flow and volumes collected.

(e) The oral flora resulting in a true change from a caries-active to a caries-free phase during the actual sampling period.

(f) The clumping of the bacterial cells so that one cell does not give rise to one colony; the counting of colonies thus gives an inaccurate estimation.

(g) The human factor in the carrying out of the laboratory procedures, in particular in the counting of colonies on the tomato agar plates.

The collection of three samples per child in one week should tend to lessen the effect of some errors. However, the important point is that the tests, with all their potential errors, are applied to the two groups, sugar and control, and therefore the errors are common to both. It is relevant to remark that the procedures of Hadley (1933) and Snyder (1940) were not altered, so that any data which were obtained could be compared with the results of the American workers who use these tests. Both Hadley and Snyder use the tests to forecast future carious lesions, claiming that a high score indicates present caries activity. An examination of this claim will be the subject of a separate communication.

The possibility that rate of flow and volume of saliva collected might affect the results was considered. A group of children were each given two bottles

marked A and B. For the first 3 minutes of collection, bottle A was used. Bottle B was then substituted, and collection completed after a further 3 minutes. The readings were the same for each sample. This result appears to be supported by the work of Feirer and Leonard (1931), who found that after as many as 40 rinses with 25 ml. of water the bacterial population was only reduced to just below half the original number.

In so far as the Snyder test shares the same method of saliva collection it may be criticized. The test itself, however, is less open to criticism. The laboratory procedures are very simple and are unlikely to give rise to great inaccuracies. The use of the shake culture provides conditions of growth for both aerobic and micro-aerophilic organisms.

An examination of the individual readings for this test shows that the variation between the three samples in the one week is slight.

Results

(*a*) *Lactobacillus count*. A separate analysis was carried out for the 84 children who were present at both the June 1949 and September 1950 examinations. Of these, 45 children (12 boys and 33 girls) were in the sugar group and 39 children (11 boys and 28 girls) in the control group.

The average values of the lactobacillus scores were as follows:

	June 1949	*September* 1950
Sugar group ..	1·16	1·87
Control group ..	1·13	1·92

Neither at the beginning nor at the end of the 15 months' survey was there any significant difference between the sugar and the control groups, but the lactobacillus score had risen significantly in both groups. Thirty-five children of the sugar group and 32 children of the control group were still present at the June 1951 examination when the average scores for sugar and control groups were 1·46 and 1·41 respectively. Again there was no difference between the two groups though both groups still showed average lactobacillus scores which were significantly above the June 1949 values but lower than those for 1950.

In a more detailed analysis, all the children have been classified with regard to their initial lactobacillus score (Table 20).

TABLE 20

Lactobacillus scores, initially, after 15 *months and after* 2 *years*

Time of analysis	Group	Children having initial lactobacillus scores of:										Total no. of children	Average lact. score
		0		1		2		3		4			
		No.	Average lact. score	No.	Average lact. score	No.	Average lact. score	No.	Average lact. score	No.	Average lact. score		
ginning survey	Sugar	20	0·0	8	1·0	7	2·0	10	3·0	0	—	45	1·16
	Control	17	0·0	7	1·0	9	2·0	5	3·0	1	4·0	39	1·13
er 15 onths	Sugar	20	1·7	8	1·6	7	1·7	10	3·6	0	—	45	1·87
	Control	17	1·5	7	1·7	9	2·3	5	2·6	1	4·0	39	1·92
er 2 ars	Sugar	20	1·1	6	2·0	5	1·4	4	2·5	0	—	35	1·46
	Control	16	1·1	5	1·4	8	2·1	3	1·0	0	—	32	1·41

(*b*) *Snyder's colorimetric test*. Again a separate analysis was carried out for the 84 children who were present at both the June 1949 and September 1950

examinations, of whom 45 were in the sugar group and 39 in the control group. The average values of the Snyder test scores were as follows:

	June 1949	*September* 1950
Sugar group ..	1·09	2·20
Control group ..	1·18	2·28

Again there is no significant difference between the sugar and control groups at either the beginning or the end of the survey, but the average Snyder test score has risen significantly during the 15 months' survey.

Thirty-five children of the sugar group and 32 of the control group were still present at the September 1951 examination when the average scores for the sugar and control groups were 1·74 and 1·81 respectively, which are still significantly above the June 1949 values. A more detailed analysis is given in Table 21.

TABLE 21

Snyder test scores, initially, after 15 *months and after* 2 *years*

Time of analysis	Group	Children having initial Snyder scores of :										Total no. of children	Aver. Snyd sco
		0		1		2		3		4			
		No.	Average Snyder score	No.	Average Snyder score	No.	Average Snyder score	No.	Average Snyder score	No.	Average Snyder score		
Beginning of survey	Sugar	25	0·0	6	1·0	3	2·0	7	3·0	4	4·0	45	1·0
	Control	20	0·0	4	1·0	6	2·0	6	3·0	3	4·0	39	1·1
After 15 months	Sugar	25	1·9	6	2·3	3	3·0	7	2·9	4	2·3	45	2·2
	Control	20	1·9	4	1·5	6	2·8	6	3·0	3	3·0	39	2·2
After 2 years	Sugar	23	1·3	3	3·0	2	2·0	4	3·0	3	2·0	35	1·7
	Control	16	1·3	3	2·7	6	2·2	6	2·2	1	3·0	32	1·8

(*c*) *Relation between lactobacillus score and Snyder test score.* It will be noted from sections (*a*) and (*b*) that the results for the above scores are very similar. Indeed, there is a correlation between these scores, as is shown in Table 22 below in which all 260 pairs of determinations of the lactobacillus count and the Snyder test carried out on the same child at the same time have been assembled and are classified with regard to the scores of the two tests. The correlation coefficient is 0·77.

TABLE 22

Correlation between 260 *pairs of determinations of lactobacillus count and Snyder test score*

Snyder test score	Lactobacillus score					Total pairs of determinations
	0	1	2	3	4	
0	75	11	10	1		97
1	14	2	4	2		22
2	8	9	11	5	1	34
3	4	5	32	31	10	82
4			2	13	10	25
Totals	101	27	59	52	21	260

Conclusions

During the course of the investigation there were increases in lactobacillus counts and in Snyder test scores in both the sugar and the control groups. There were, however, no significant differences between the results obtained for the two groups. We can conclude, therefore, that in this investigation the additional sugar in the diet has had no effect on the lactobacillus counts or the Snyder test scores.

B. BUFFERING CAPACITY OF SALIVA

One of the factors which will offset the effects of acid production in the mouth is the buffering capacity of saliva. Several workers have investigated this problem. Karshan (1936) found that the salivas of caries-free subjects when compared with caries-active subjects had higher mean values for neutralizing power against acid.

More recently Dreizen, Mann, Cline and Spies (1946) have determined the buffering capacity of saliva as a measure of caries activity. They found that saliva from subjects with rampant caries had less buffering power between pH 7 and 6 than saliva from caries-immune subjects.

Wills and Forbes (1939) reported that a diet low in carbohydrate and high in protein increased the neutralizing power of the saliva, and that a high carbohydrate diet lowered its neutralizing power.

In the present investigation the children were not likely to include a high percentage of either caries-immune or caries-rampant cases. It was, however, considered of interest to find out whether increasing the sugar in the diet would influence the buffering capacity.

The object was to try to answer the following questions:

1. Is there an increase in buffering capacity with increasing age?
2. If so, is there a greater increase in the control group than in the sugar group?
3. Is there any correlation between the incidence of caries (irrespective of diet) and buffering capacity?

For this purpose 24 comparable pairs of children were selected. Girls only were chosen since it was known that they were less likely to leave the home than the boys. Observations were made in September 1949, January and July 1950, and July 1951. In the sugar and control groups 18 and 19 girls respectively were observed throughout the investigation.

Collection of Saliva Samples

The only time when all the children were available was immediately after their midday meal. There are disadvantages in collecting saliva at this time, but it was considered a justifiable expedient and was moreover a measure of buffering capacity under stress. Saliva was collected in previously sterilized 25 ml. screw-capped bottles. Each child was given a piece of paraffin wax (B.D.H. m.p. 49° C.) to stimulate the flow of saliva and instructed to fill the bottle up to a 10 ml. mark. The children replaced the screw cap after each expectoration. The collection time varied between 5 and 15 minutes. A supervisor was always present. The samples were then placed in an ice-box and taken immediately to the laboratory. Saliva was collected from one half of each group on the Monday and duplicate samples taken on the Wednesday of the

same week. Samples were obtained from the remaining children on the same days of the following week.

The buffering capacity of the saliva was determined electrometrically using a Cambridge pH meter with glass electrode, and was expressed as the number of ml. of 0·1 N lactic acid required to lower the pH of 5 ml. of saliva from 7 to 6. The whole operation was completed in 3 hours. If the samples were kept at a temperature below 10° C. in their screw-capped bottles it was found that there was no appreciable change in buffering capacity over a period of 4 hours. In 171 determinations only 4 salivas had a pH less than 7; these were 6·96, 6·73, 6·86 and 6·84. The values in these cases were estimated by extrapolation of the titration curves. The error introduced in this way is very small, and it was considered more satisfactory to extrapolate than to adjust the pH to 7 before titration. The initial pH of the saliva samples was probably a little higher than *in vivo* owing to loss of dissolved CO_2. It is difficult to avoid this loss under field conditions.

Results

Table 23 gives the number of girls present at each examination and their average buffering capacities. The over-all range in buffering capacity was 0·3 to 0·9.

TABLE 23

Average buffering capacities of sugar and control groups

	September 1949	January 1950	July 1950	July 1951
Sugar group:				
No. of girls	24	23	22	18
Average buffering capacity	0·479	0·491	0·503	0·522
Control group:				
No. of girls	24	21	20	19
Average buffering capacity	0·518	0·465	0·526	0·585

A separate analysis of variance was carried out for 24 girls of the sugar group and for 21 girls of the control group. For most of these girls the buffering capacity was determined at each of the four examinations—September 1949,

TABLE 24

Analysis of variance

Source of variation	Sugar group		Control group	
	Mean square*	Degrees of freedom*	Mean square*	Degrees of freedom*
Between girls	0·0313	23	0·0980	20
Between times of determination	0·0068	3	0·0498	3
Experimental error	0·0065	60	0·0060	57

* The terms 'mean square' and 'degrees of freedom' are to be taken in their accepted statistical sense, the latter being worked in accordance with the 'missing value analysis'.

January 1950, July 1950, July 1951. For certain girls the determination was not available on some of the above dates and the data were therefore analysed by the 'missing value analysis'. Table 24 shows the analysis of variance.

In both groups there were highly significant differences between individual girls. This means that the technique of determining buffering capacity was sufficiently accurate to reproduce relative differences in the buffering capacity of individual girls to fair consistency at each of the four examinations.

There was a slight tendency for the buffering capacity to increase during the 21 months of this survey. In view of the considerable variation of this measurement between individual girls it was considered advisable to analyse separately the data for the 37 girls who stayed throughout the 21 months of the survey. The figures for these girls are given in Table 25.

TABLE 25

Separate analysis of buffering capacities of 37 girls staying throughout the 21 months of the survey

	September 1949	July 1951	Average increase in buffering capacity per quarter	Standard error
Sugar group:				
No. of girls	18	18		
Average buffering capacity	0·484	0·522	0·0054	0·0027
Control group:				
No. of girls	19	19		
Average buffering capacity	0·513	0·585	0·0103	0·0038

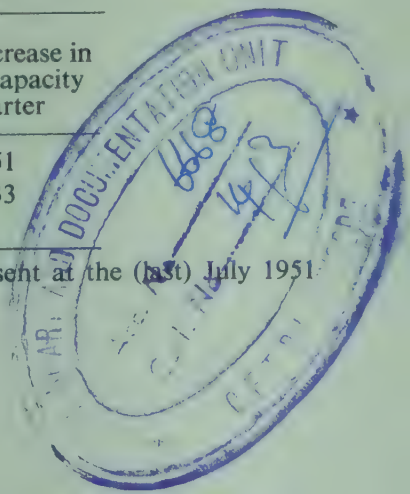
In the third column of Table 25 are shown the respective average increases (per quarter) of the buffering capacity in both sugar and control groups. The control group shows an increase which is clearly significant, whilst that of the sugar group is only just significant; the difference between the two groups' increase figures is not significant. These tests were confirmed by a more detailed analysis in which the growth of the buffering capacity in each child was represented by a linear growth-curve which was fitted to the four results available for each child. The resulting values of average growth-rate of buffering capacity were then compared for the two groups, with results similar to the above. The average growth-rate figures from this analysis are shown in Table 26.

TABLE 26

Average growth-rate figures of buffering capacity

	No. of girls	Average increase in buffering capacity per quarter
Sugar group	18	0·0051
Control group	18*	0·0133

* One girl who missed the July 1950 examination but was present at the (last) July 1951 examination is excluded from this analysis.



Since we have found that the buffering capacity in the control group has risen significantly during the 21 months of the survey it is of interest to inquire whether there is a tendency for older children to have a higher buffering capacity. The evidence on this point from the present data is limited, as the age differences are small. In Table 27 we set out the averages of the buffering capacity determined in September 1949 for each of the three age-groups in both sugar and control groups.

TABLE 27

Average buffering capacity in the three age-groups

Year of birth	Approximate age (years)	Sugar group			Control group		
		No. of girls	Average buffering capacity	Standard error	No. of girls	Average buffering capacity	Standard error
1938	11	8	0·45	0·06	8	0·60	0·11
1939	10	8	0·49		8	0·45	
1940	9	8	0·50		8	0·50	

The standard errors (computed from the 'Between girls Mean squares') indicate that, in view of the large differences between individual girls, no significant differences are shown in the above table. This shows that any rise in buffering capacity with age can only be established by following up the records of the *same* subject. It is possible, of course, that the increase in buffering capacity during the experimental period is not related to age. It may be due to some other external condition which has altered during the investigation.

Correlation between Buffering Capacity and Incidence of Caries

This part of the inquiry is incidental to the main investigation and is not concerned with the effect of the additional sugar. The question now under consideration is whether a comparatively low value of the buffering capacity is associated with a high incidence of caries.

For this purpose it appeared most appropriate to use an examination at which both the buffering capacity of the saliva was determined and the teeth were examined clinically. Such records are in fact provided by the January 1950 examinations. When the sugar and the control groups were pooled, 44 girls' records were available and buffering capacity was correlated with the following measures of caries index:

(a) The A.C.F. for permanent molars $\frac{6/6}{6/6}$

(b) The D.M.F. value for permanent molars $\frac{6/6}{6/6}$

The correlation coefficients obtained are as follows:

Correlation coefficients of buffering capacity with:

(a) A.C.F. for $\frac{6/6}{6/6}$	(b) D.M.F. for $\frac{6/6}{6/6}$
–0·167	–0·162

Although the negative correlation coefficients suggest that a high incidence of caries is associated with a low buffering capacity, neither of these correlation coefficients is significantly different from 0.

In the case of the D.M.F. scores there may further be some doubt as to whether these counts follow a normal distribution. Any possible association has therefore been checked (see Table 28).

TABLE 28

Relationship between D.M.F. score and buffering capacity

D.M.F. for $\frac{6/6}{6/6}$	Buffering capacity	
	Under 0·50	0·50 and over
0 or 1	10	8
2, 3 or 4 ..	17	9

Although there is a slight tendency for lower values of the buffering capacity to occur with children with a higher D.M.F. value, the value of X^2 for Table 28 is 0·43 and clearly not significant.

Conclusions

Increase in buffering capacity with increasing age. During the 18 months of the investigation there was a significant increase in the buffering capacity of the saliva, the increase being larger in the control than in the sugar group. While this may suggest that the extra sugar retarded the increase in buffering capacity with age, the difference in the respective rates of increase of buffering capacity of the two groups is not significant.

Relationship between buffering capacity and caries. The correlation coefficients of buffering capacity with the incidence of caries were not significantly different from 0 when either A.C.F. or D.M.F. figures were used. The coefficients were, however, both negative (–0·167 and –0·162), which may suggest that the incidence of caries is associated with low buffering capacity.

APPENDIX II

Preliminary Trials of Sugar Tolerance

As mentioned on p. 2, a few preliminary trials were made before the investigation was begun, to see how much unrefined sugar young children could take with ease over a period of several weeks.

Three tests were made in private families; each was designed to last for four weeks and unrefined sugar was to be given at the rate of 1, 2, 2 and 1 lb. per child per week, in successive weeks.

In Liverpool three children, aged 3, 6 and 8 years, took part in the trial. White sugar was discontinued and replaced by the unrefined variety, which was used in cooked foods as far as possible and was also given directly on cereals. The children ate the sugar well for the first two weeks, but during the third week tired of it and preferred stewed fruit without sugar rather than with the unrefined sugar. In the fourth week each child consumed less than half its allocation. When white sugar was offered, however, it was readily accepted.

Two Sheffield children, aged 3 and 5 years, were also given unrefined sugar in place of the refined sugar they ordinarily ate, and were unaware of the change. One child had to withdraw from the test at the end of the second week because of illness (unassociated with the sugar), but the other completed the third and fourth weeks satisfactorily. It was felt by the parents that variety in the method of giving the sugar was probably an important factor in its successful administration.

In a test made in Cambridge two children, aged $5\frac{1}{2}$ and $8\frac{1}{2}$, had the unrefined sugar in addition to their usual ration (war-time rationing of sugar was still in force). They ate the full allocations, largely made into sweetmeats, with little difficulty, except that they began to show a slight reluctance towards the end of the fourth week.

Eight children, aged 3 to 6 years, living in a German orphanage where investigations were being carried out for the Medical Research Council, also took part in the sugar trials. They had the ordinary institutional diet with additional sugar, four having unrefined and the other four refined sugar, which they ate on bread and butter. The trial lasted for six weeks and during this time it was found that the average amounts of both varieties of additional sugar eaten were approximately equal, varying from 9 to 12 oz. per child per week. It was also observed that before the end of the period they were not eating the sugar as willingly as at the beginning. It was felt that probably the total amount of sugar and sweetmeats that might be eaten weekly by such children, in addition to the sugar contained in the institutional diet, would be about 1 to $1\frac{1}{4}$ lb.

The general conclusion from these tests was that 1 lb. of unrefined sugar per week and perhaps more of white, in addition to the ration contained in their usual diet, could probably be tolerated by most children in England.

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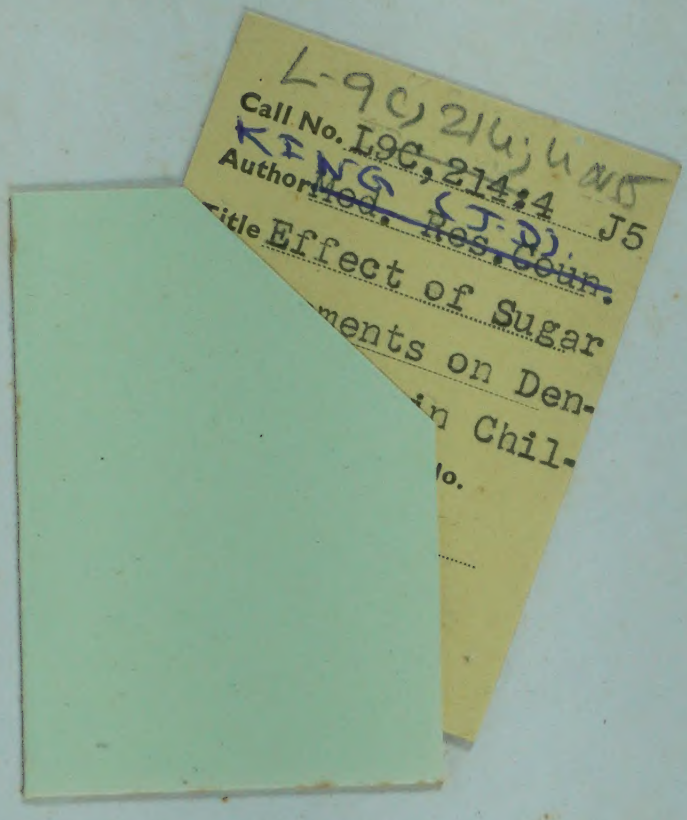
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